WATER-QUALITY VARIABILITY IN FOUR RESERVOIRS IN PHILLIPS AND VALLEY COUNTIES, MONTANA, MAY THROUGH AUGUST 1981

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CONVERSION FACTORS

The following factors can be used to convert from the International System of Units (SI) in this report to the equivalent inch-pound units.

Multiply SI unit	By	To obtain inch-pound unit
hectare (ha)	2.471	acre
kilometer	0.6214	mile
liter (L)	33.82	ounce, fluid (oz)
meter (m)	3.281	foot
milliliter (mL)	0.0338	ounce (fluid)
millimeter (mm)	0.0394	inch
square kilometer	0.3861	square mile
square meter (m^2)	10.76	square foot

Temperatures in degrees Celsius (°C) can be converted to degrees Fahrenheit (°F) by the formula:

$$°F = 9/5\ (°C) + 32$$

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ABSTRACT

Four reservoirs in Phillips and Valley Counties were studied from May to August 1981 to describe: (1) the variation in water quality that occurs from late spring (May) to late summer (August) and during 24 hours in late summer (August), and (2) possible causes for water-quality variation during these periods. The reservoirs represent considerable ranges of water quality and reservoir age that exist for many similar reservoirs in eastern Montana. Although there are similarities in water quality of reservoirs from the same regional mineralogy, differences in water quality caused by local mineralogy and land use mask differences caused by reservoir age.

All the reservoirs had distinct thermal gradients but lacked true stratification as a result of circulation induced by the wind. Such mixing helps prevent oxygen depletion in bottom waters during the summer. Dissolved-oxygen gradients existed in all the reservoirs, with the smallest concentrations occurring in the near-bottom water of the reservoirs and during the night. Nighttime dissolved-oxygen concentrations in reservoirs 19 and 24 were less than in reservoirs 1 and 9. Similar trends occured with pH. The fluctuations in dissolved-oxygen concentration and pH most likely result from variation in phytoplankton and zooplankton concentrations detected in conjunction with decomposition of organic matter in the bottom sediments.

Most chemical constituents in the water generally became more concentrated from May to August because of cumulative water losses through evapotranspiration. However, this condition was most evident with the major dissolved constituents. Reservoir 19 had sodium bicarbonate sulfate water, reservoirs 1 and 24 had sodium bicarbonate water, and reservoir 9 had sodium sulfate water. Major dissolved constituents and nutrients had little change in concentration during diel sampling. Results of biological analyses were variable. All four reservoirs contained similar types of planktonic organisms but in different proportions. A common pattern for phytoplankton concentrations was a slight increase between the June and July sampling and a decrease from the early to late August sampling. The total number of benthic invertebrates were fewer in reservoir 9 than in reservoirs 1, 19, and 24. However, reservoir 9 had a more diverse benthic community than the other reservoirs. There were no consistent trends in bacterial or zooplankton concentrations among the study reservoirs.

Major water-quality changes that occurred in the reservoirs could affect proposed uses of the study reservoirs. August concentrations of lead and nighttime concentrations of dissolved oxygen in reservoirs 19 and 24 exceeded the criteria protective of fish. Late afternoon pH in all reservoirs approached or exceeded the maximum limits protective of fish propagation, waterfowl habitat, livestock watering, and recreational swimming.

INTRODUCTION

Twenty-four reservoirs (fig. 1) in Phillips and Valley Counties were sampled in 1978 and 1979 to characterize their water quality and to evaluate their suitability for fish propagation, waterfowl habitat, livestock watering, and recreational use. Most of the reservoirs are formed by earthen dams constructed by the U.S. Bureau of Land Management. Reservoir surface areas ranged from 0.2 to 146 ha and maximum reservoir depths ranged from 0.05 to 6.5 m.

To evaluate each of the 24 reservoirs, water-quality data were collected once during each limnologically extreme period: late winter, late spring, late summer, and early autumn. The data then were compared to a set of criteria protective of each proposed use (Ferreira, 1983). Several of the reservoirs were suitable for all the proposed uses; a few of the reservoirs had water quality that indicated unsuitability for all uses. All the reservoirs generally were enriched with nutrients (eutrophic) and, therefore, had the potential for massive algal blooms and suppressed dissolved-oxygen concentrations (Ferreira, 1980; 1983). The resultant small dissolved-oxygen concentrations could be stressful to fish.

Compared to other times of the year, early spring and late summer commonly are periods of greatest phytoplankton production in lakes and reservoirs, mostly because of increased nutrient availability after spring snowmelt and subsequent warm-water temperatures and long days in late summer (Reid and Wood, 1976). During the summer, thermal stratification and succession of plant and animal populations can augment the variability in chemical water quality. In enriched lakes, water quality can vary considerably during 24 hours as a result of changes produced by photosynthesis, respiration, and decomposition.

To gain a better understanding of the variation, the U.S. Bureau of Land Management entered into a cooperative program with the U.S. Geological Survey in 1981 to investigate May through August and diel (24-hour) changes in water quality in selected reservoirs that had been sampled in 1978 and 1979. Data from this study supplement the quarterly information obtained in 1978 and 1979.

Purpose and scope

The purpose of this report is to describe for four selected reservoirs: (1) the variation in physical, chemical, and biological quality of water occurring approximately monthly from late spring (May) to late summer (August) and during 24 hours in late summer (August) of 1981, and (2) possible causes for water-quality variation during these periods. Although only a subset of the reservoirs sampled in 1978 and 1979 was sampled for this study, there is enough difference within the subset that observed changes in water quality would be representative of similar changes in the remaining reservoirs. The four study reservoirs were chosen pri-

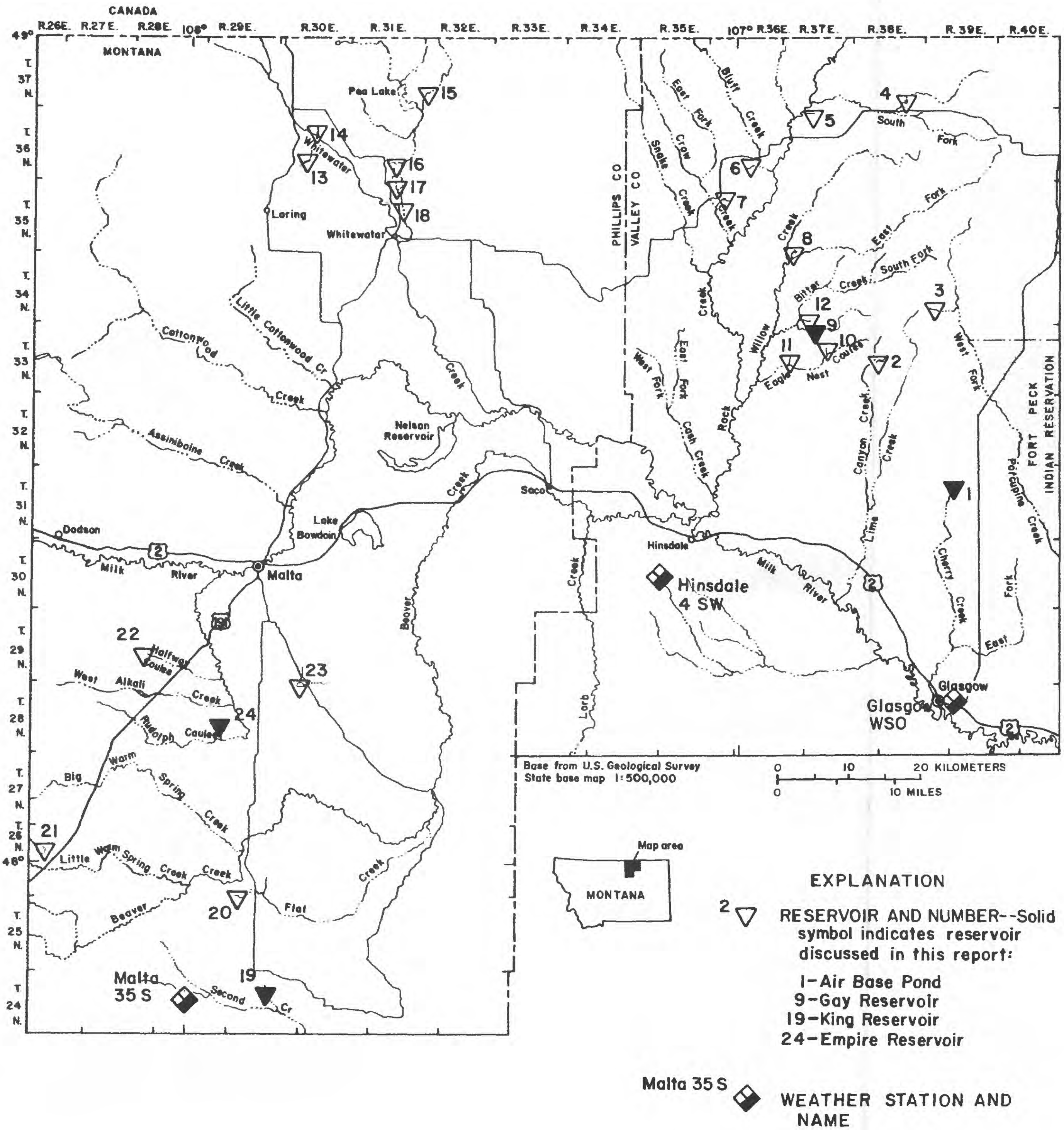

Figure 1.--Location of study area and reservoirs at which water-quality data were collected in 1978, 1979, and 1981.

marily on the basis of being average in size among the reservoirs sampled in 1978 and 1979 and of representing considerable ranges in water quality and reservoir age. In 1981, the study reservoirs ranged in age from 9 to 44 years. Reservoirs of different age could provide information that would be helpful in determining the possibility of managing each reservoir through a succession of uses associated with different stages of eutrophication. For example, young reservoirs might be suitable for cold-water fisheries and eventually progress through stages more suitable for warm-water fisheries, waterfowl habitat, and finally livestock watering. The May through August and diel variability in water quality described in this report is intended to be useful for development of long-term management strategies of similar U.S. Bureau of Land Management reservoirs.

Samples were collected monthly from May through July and twice in August; during sampling, depth profiles of temperature, dissolved oxygen, pH, and specific conductance were measured. Water-quality samples were analyzed for major dissolved constituents, selected plant nutrients, and selected trace elements. Biological samples were analyzed for phytoplankton, zooplankton, benthic invertebrates, and bacteria.

During 24 hours in late August, water temperature and dissolved oxygen were recorded continuously, and pH and specific conductance were measured 10 times at a depth of 1 m. Vertical profiles of water temperature, dissolved oxygen, pH, and specific conductance were measured and water samples for chemical and biological analyses were collected twice during the 24 hours.

Study area

The location of the study reservoirs is shown in figure 1. Topography generally is flat except for breaks along the larger streams. Grasses cover most of the landscape, and willow (*Salix* sp.) and cottonwood (*Populus* sp.) trees are abundant in localized areas where water is sufficient for growth. The area generally is used for livestock grazing.

The drainage of each reservoir transects the Bearpaw Shale of Late Cretaceous age (Ross and others, 1955). The Bearpaw Shale is a dark-gray and brown clay shale, which forms gumbo soil when wet. Although much of the drainage overlies the Bearpaw Shale, reservoir 1 also overlies the Flaxville Formation of late Tertiary age. This unit is a brown, yellow, and gray deposit of gravel, sand, and silt with local areas of marl and volcanic ash. A small part of the drainage area for reservoir 9 overlies the Judith River Formation of Late Cretaceous age, which is a light-colored sandstone near the top underlying the Bearpaw Shale and a dark-gray siltstone and sandy shale near the bottom.

The setting and general size of the reservoirs are similar to the many "prairie pothole" lakes that abound in the Upper Midwest (Barica, 1974; Eisenlohr and others, 1972). Generally, "prairie pothole" lakes are shallow (1 to 5 m deep), have no permanent outflow, have no strong thermal stratification (characterized by three regions of different temperatures), and are extremely eutrophic (Barica, 1974). The study reservoirs have surface areas less than 4.0 ha and depths less than 7.0 m. The two older reservoirs (1 and 19) are larger in surface area and deeper than the two newer reservoirs (9 and 24) (table 1).

Table 1.--*Location, construction date, and physical characteristics of the reservoirs*

Reservoir		Location			Year dam constructed	Drainage area (square kilometers)	Full-pool surface area (hectares)	Measured depth at sampling location (meters)	
Number (fig. 1)	Name	Latitude	Longitude	Land-line description				Minimum	Maximum
				Valley County					
1	Air Base Pond	48°26'40"	106°35'30"	T. 31 N., R. 39 E., sec. 18	1942	2.15	2.7	3.5	6.5
9	Gay Reservoir	48°38'30"	106°51'10"	T. 33 N., R. 37 E., sec. 2	1972	.91	1.3	1.2	4.7
				Phillips County					
19	King Reservoir	47°51'00"	107°51'30"	T. 24 N., R. 30 E., sec. 15	1937	1.22	3.8	3.0	5.3
24	Empire Reservoir	48°09'50"	107°58'00"	T. 28 N., R. 29 E., sec. 22	1968	2.23	1.8	1.1	2.3

Among the four study reservoirs, only reservoir 1 has extensive growths of woody plants, and these occur along its south and southeast shore. The rock-faced earthen dam of reservoir 19 is covered with a dense growth of wild-rose bushes. However, most of the perimeters of reservoirs in Phillips and Valley Counties are covered with grasses. Compared to reservoirs 1, 19, and 24, reservoir 9 is located in a more deeply incised drainage. Reservoirs 1 and 19 are easily accessible and have been developed as recreational sites. Along the north shore of reservoir 1 are recreational facilities. Portable toilet facilities are provided at reservoir 19 during the summer.

The climate of the study area can be described as continental with hot summers and cold winters. Annual mean air temperatures at weather stations in the study area range from 2.4 to 5.2°C. The warmest month generally is July, with monthly mean temperatures ranging from 18.1 to 21.3°C. January, which generally is the coldest month, has monthly mean temperatures that range from -15.2 to -13.3°C (U.S. Department of Commerce, 1965). Six to 12 cold waves, commonly accompanied by strong winds and blowing snow, usually move through the study area each winter.

The summers are typified by frequent rainshowers and numerous windy periods (Cordell, 1971). Mean annual precipitation at weather stations within the study area ranges from 289 to 340 mm. Generally one-half of this precipitation falls during May, June, and July. Snowfall normally occurs between November and March.

Daily precipitation that occurred from May to August 1981 at weather stations (fig. 1) near each study reservoir is shown in figure 2. Included in the illustration is the cumulative precipitation that occurred between sampling dates. Monthly departures from normal (30-year average) precipitation amounts were available only for the Glasgow WSO weather station near reservoir 1. Generally, precipitation was about 25.4 mm less than normal from May through August of 1981, and for the 4 months prior to the study. By the end of the study, reservoirs 19 and 24 had received the most precipitation among the reservoirs.

Water gains to prairie reservoirs occur principally by overland runoff and ephemeral flow from precipitation and by ground-water inflow. Water losses from the reservoirs occur by seepage through and around each dam, evaporation from the water surface, and transpiration by aquatic and riparian vegetation. As a measure

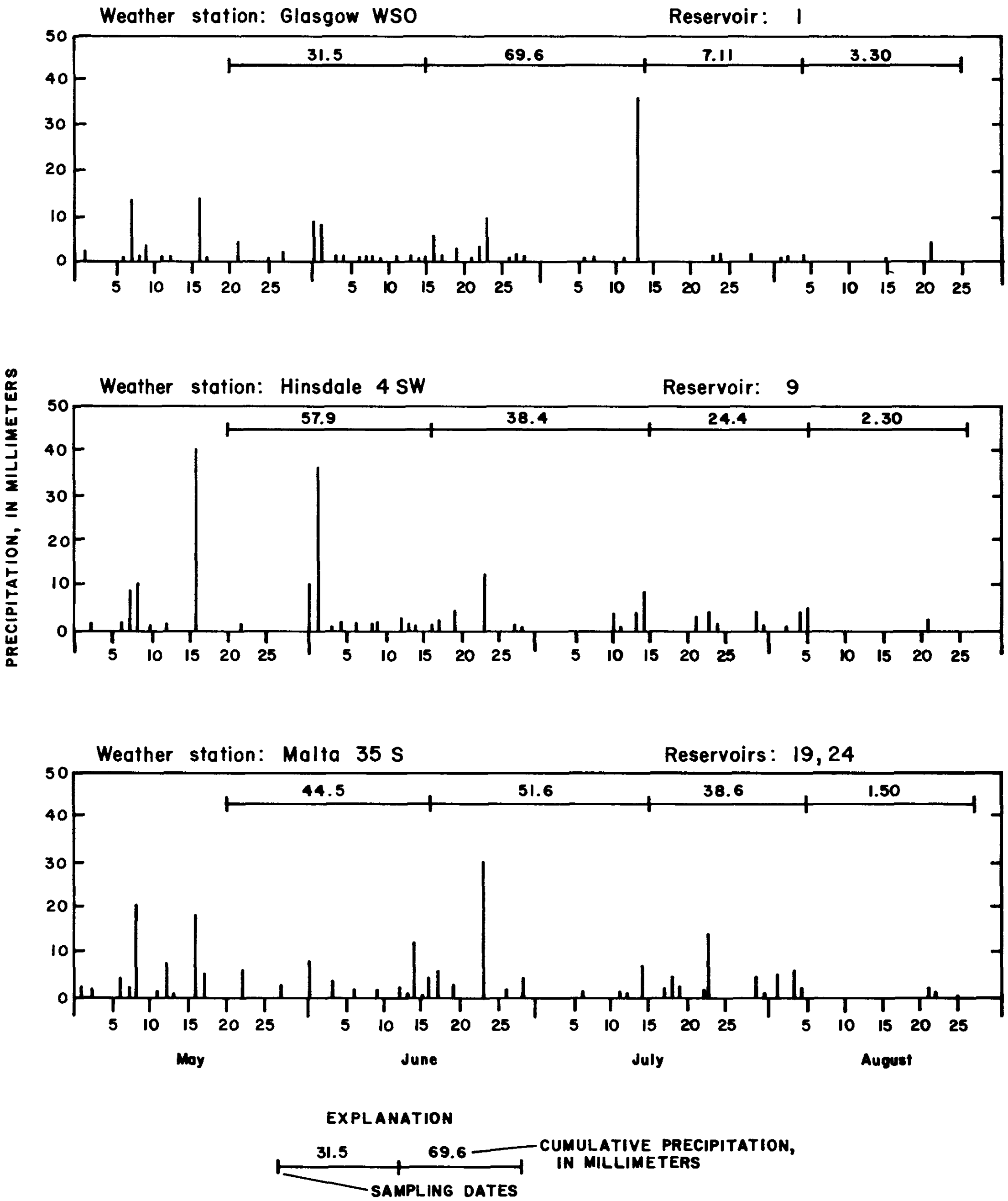

Figure 2.--Daily precipitation at three weather stations from May to August 1981 and cumulative precipitation between five sampling dates.

of the overall effect of water gains and losses, changes in water-surface elevation from the May sampling were recorded for each reservoir (fig. 3). The water-surface elevation loss in reservoir 9 was the largest among the reservoirs. Because of various surface- and ground-water inflow rates, water losses, and drainage area sizes, declines in the water surface do not correlate with total precipitation that occurred among the study reservoirs.

SAMPLING METHODS AND ANALYSIS

Each of the four reservoirs was sampled approximately monthly, starting in May 1981 and ending with two samplings in August 1981. During each of the sampling periods, vertical profiles of selected water-quality variables were made and samples for chemical and biological analyses were collected. Because the largest differences in water quality between night and day commonly occur in late summer, diel sampling was conducted during the sampling period in late August.

Vertical profiles of water temperature, dissolved oxygen, pH, and specific conductance were made using a multiparameter instrument. In each reservoir, measurements were made near the dam, which was estimated to be the deepest part of the original stream channel.

At the same location as the profiles, water samples for chemical analyses were collected with an acrylic Kemmerer[1] water sampler. Where reservoir depths exceeded 2 m, near-surface (1.0 m) and near-bottom samples were collected to represent the water quality of the reservoir. In shallow reservoirs of 2 m or less, one chemical sample was collected at middepth (1.0 m) to represent the water quality of the reservoir. Care was taken not to disturb the reservoir sediment when sampling near the bottom. All samples were pretreated onsite according to methods of the U.S. Geological Survey (Friedman, 1979). Chemical constituents in water samples were analyzed at the U.S. Geological Survey laboratory in Denver, Colo., using methods described by Skougstad and others (1979).

Depth of light penetration was estimated with a Secchi disk. The depth of light penetration was considered to be the average depth of disappearance and reappearance of a black and white disk 200 mm in diameter (Hutchinson, 1967). Light penetration as a percentage of surface light also was profiled with depth, using a relative irradiance meter.

Samples for analysis of phytoplankton and zooplankton were collected from the same location as the chemical analyses. Phytoplankton and zooplankton analyses included enumeration and species identification. Phytoplankton were analyzed by Susswasser Laboratory, Paso Robles, Calif., and zooplankton were analyzed by Harner-White Ecological Consultants, Inc., Littleton, Colo.

Benthic-invertebrate samples were collected during late August in each reservoir at three locations that included deep, intermediate, and shallow water depths.

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[1] The use of named products in this report is for identification only and does not constitute endorsement by the U.S. Geological Survey.

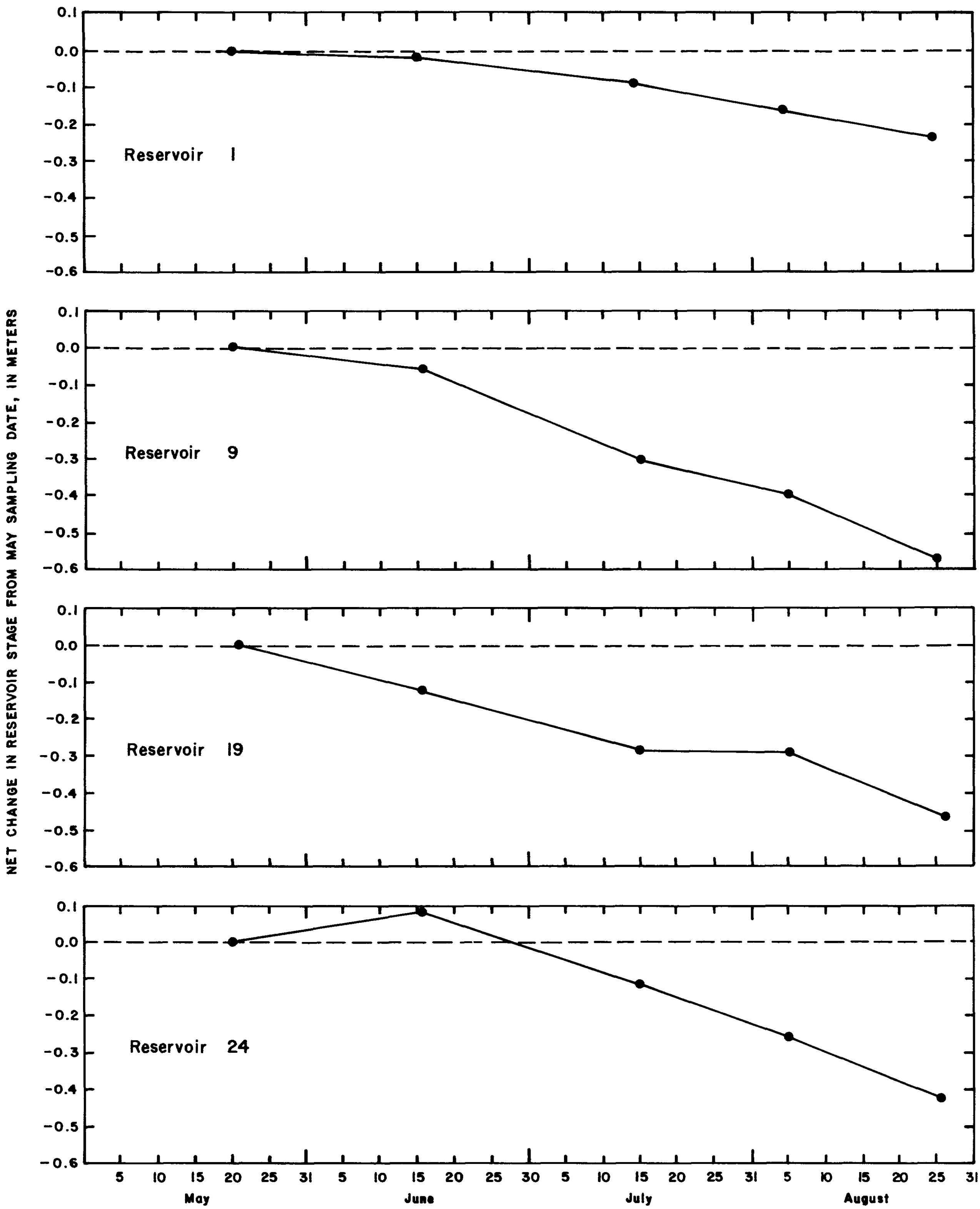


Figure 3.--Net changes in stage of reservoirs 1, 9, 19, and 24 between five sampling dates.

The sampling device used was an Eckman grab sampler having jaw dimensions of 152 x 152 mm. Benthic-invertebrate samples were analyzed by Michael Fillinger, Helena, Mont. The samples were preserved and the organisms identified to species using procedures described by Greeson and others (1977).

Water samples for total coliform, fecal coliform, and fecal streptococcal bacterial analyses were collected at the chemical sampling site and along the shore of easiest access for livestock at each reservoir. Bacteria were analyzed according to procedures described by Greeson and others (1977).

Diel sampling during late August, at the same location as the regular sampling, consisted of continuous recording of temperature and dissolved oxygen at a depth of 1.0 m. The probe of a continuous recording instrument for measuring temperature and dissolved oxygen was suspended along with multiparameter probes by floats tethered from an anchor (fig. 4). Specific conductance and pH were measured about every 3 hours during the same 24 hours as the continuous measurements. Vertical profiles of temperature, dissolved oxygen, pH, and specific conductance were obtained twice daily--about 1.5 hours before sunset and 1.5 hours before sunrise.

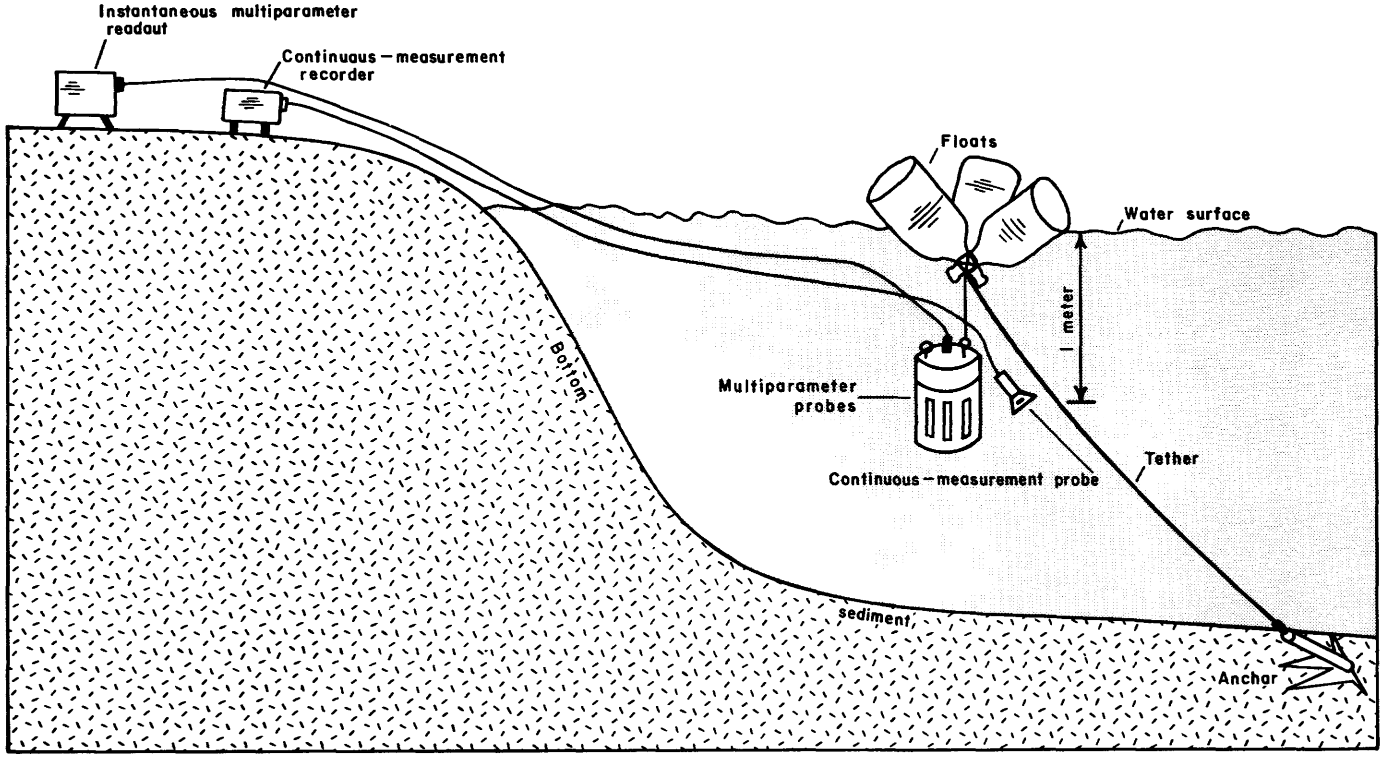


Figure 4.--Probe suspension for measurement of temperature, dissolved oxygen, pH, and specific conductance at a depth of 1 meter during the late August diel sampling.

Diel samples for major dissolved constituents, nutrients, trace elements, and chlorophyll *a* and *b* were collected at the same times as the profiles (1800 and 0500 hours). Chlorophyll *a* and *b* samples were analyzed by the U.S. Geological Survey laboratory in Denver, Colo., following methods described by Greeson and others (1977).

MAY THROUGH AUGUST TRENDS

Onsite measurements

Depth profiles of temperature, dissolved oxygen, pH, and specific conductance are described for the five sampling dates in this section of the report. Water-quality data collected during the nighttime phase of the diel sampling in late August are described in the section titled "Diel trends."

Temperature

Water temperatures during the five samplings (figs. 5-8) ranged from 12.6°C in the near-bottom water of reservoir 1 in May to 24.0°C in the near-surface water of reservoir 9 in late August. Water temperatures in the reservoirs generally followed the trend of air temperature, with the minimum temperatures occurring in May and the maximum temperatures occurring in late August. However, because of unseasonably warm temperatures during sampling in May, temperature gradients with depth generally were larger in May than in June.

Deep reservoirs have a larger heat capacity than shallow reservoirs, which allows large temperature differences to develop between the near-surface and near-bottom water as summer progresses. These large temperature differences can result in distinct density layers that resist mixing and become thermally stratified into three temperature regions: epilimnion, metalimnion, and hypolimnion. In shallow reservoirs having less heat capacity, only small temperature differences develop between near-surface and near-bottom water as summer progresses. With small temperature differences, there is less resistance to wind-induced mixing and the water does not become thermally stratified. The slight temperature gradient that occurs from the surface to the bottom in shallow reservoirs when distinct water layers do not form is termed "diminutive thermal stratification" (Wetzel, 1975).

None of the reservoirs had thermal stratification consisting of an epilimnion, metalimnion, and hypolimnion; however, at times they all had diminutive thermal stratification (figs. 5-8). Instead of increasing from May to August, the degree of temperature difference between the near-surface and near-bottom water was variable from month to month, which indicates that periods of complete mixing probably occur throughout the summer. In fact, the largest temperature differences existed in reservoirs 9 (5.2 C°) and 24 (6.0 C°) during the May sampling, which were followed by homogeneous temperature profiles during the June sampling. In addition to heat capacity, time of day probably is a determining factor in measured temperature differences between near-surface and near-bottom water. During the early morning after night-long cooling, temperature gradients may be small enough to allow total mixing by the wind. By late afternoon, the near-surface water may warm enough to resist mixing with the cooler near-bottom water.

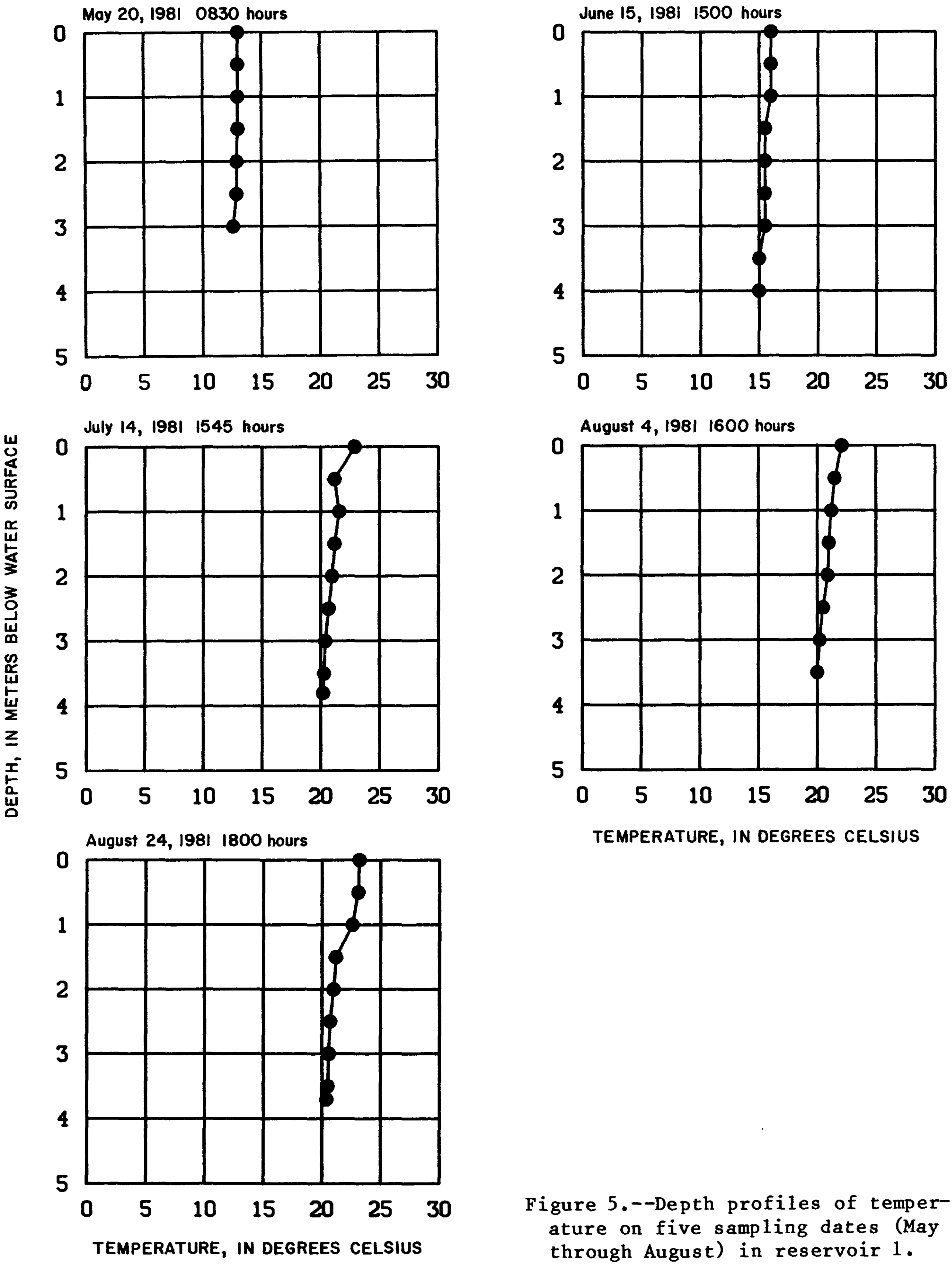


Figure 5.--Depth profiles of temperature on five sampling dates (May through August) in reservoir 1.

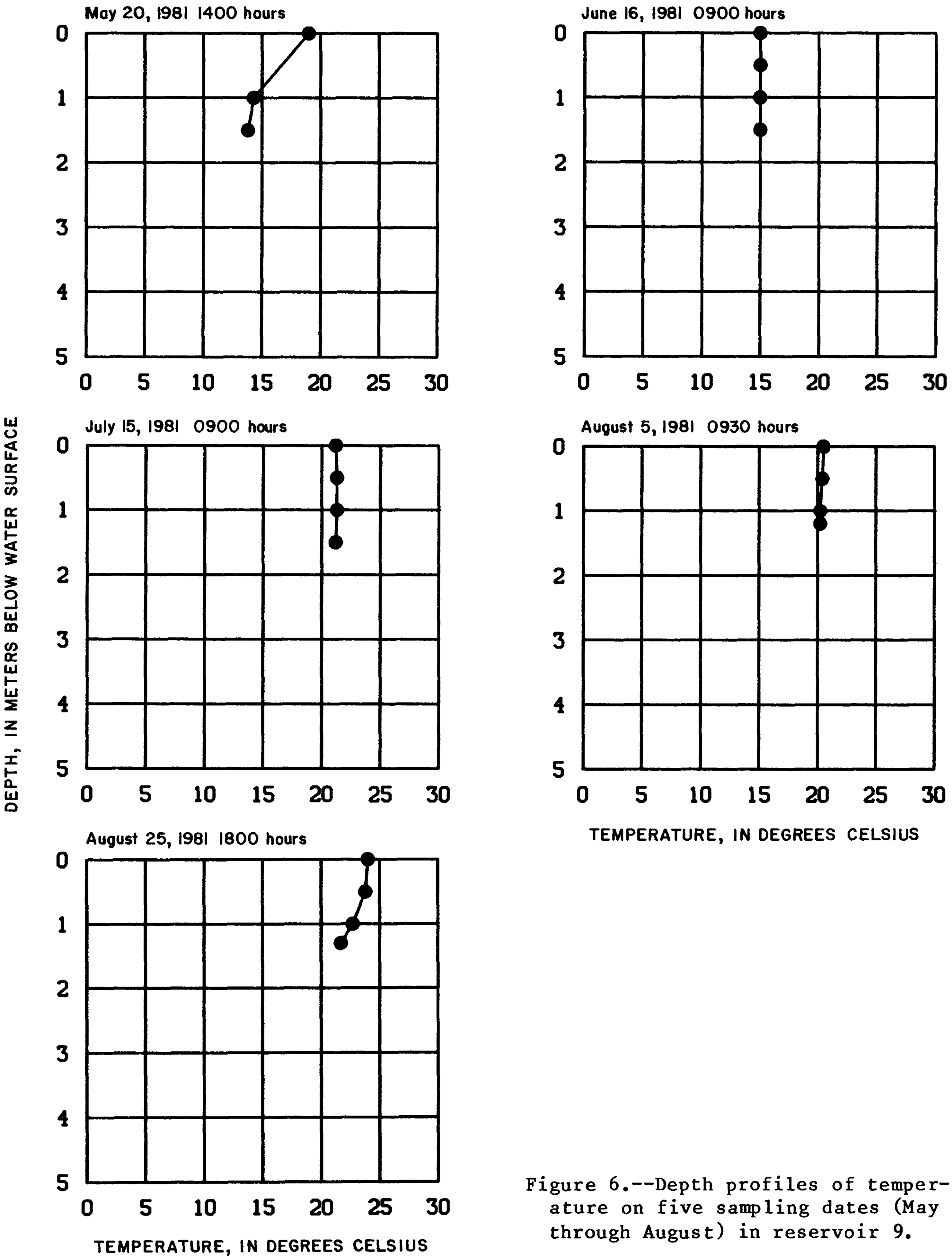


Figure 6.--Depth profiles of temperature on five sampling dates (May through August) in reservoir 9.

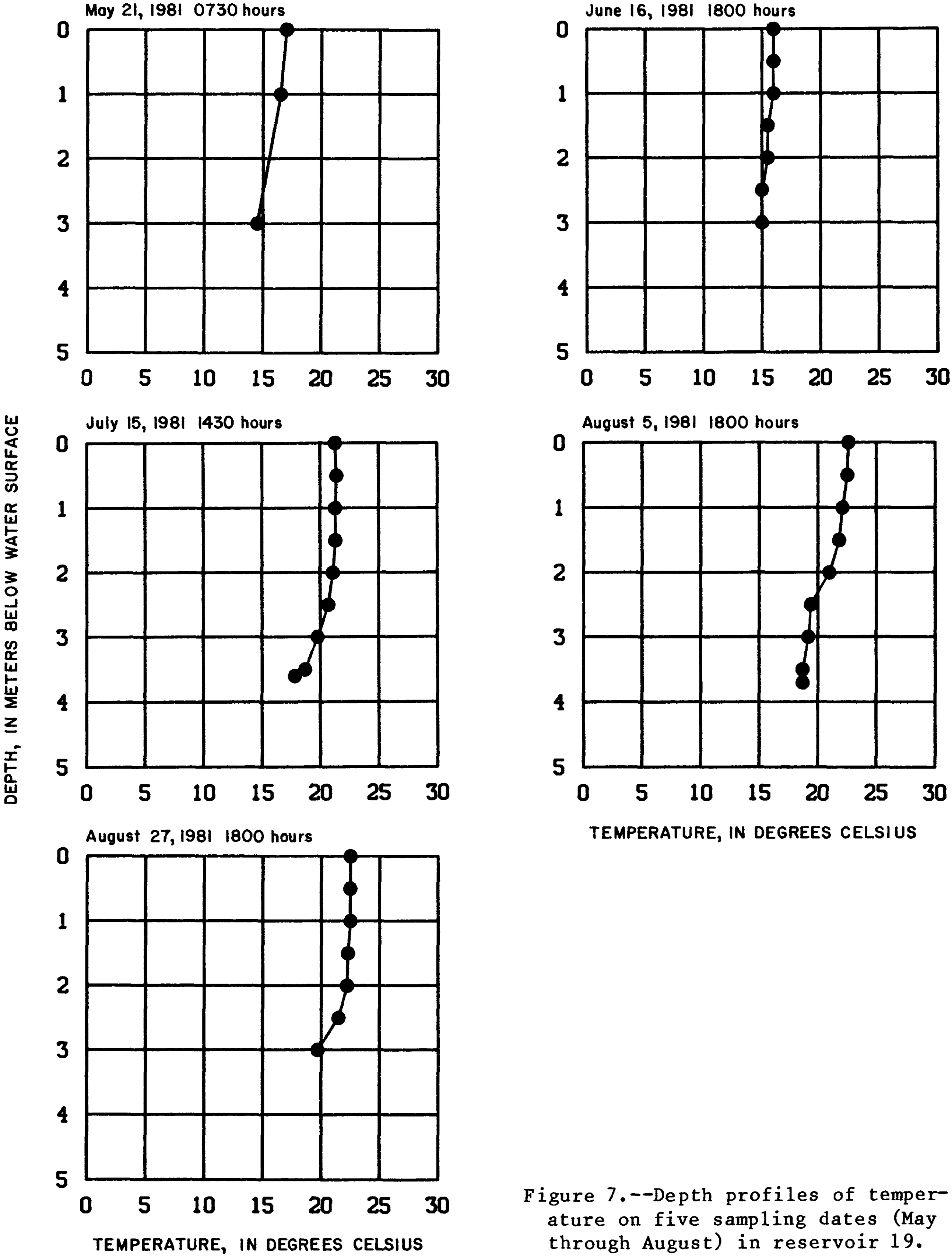


Figure 7.--Depth profiles of temperature on five sampling dates (May through August) in reservoir 19.

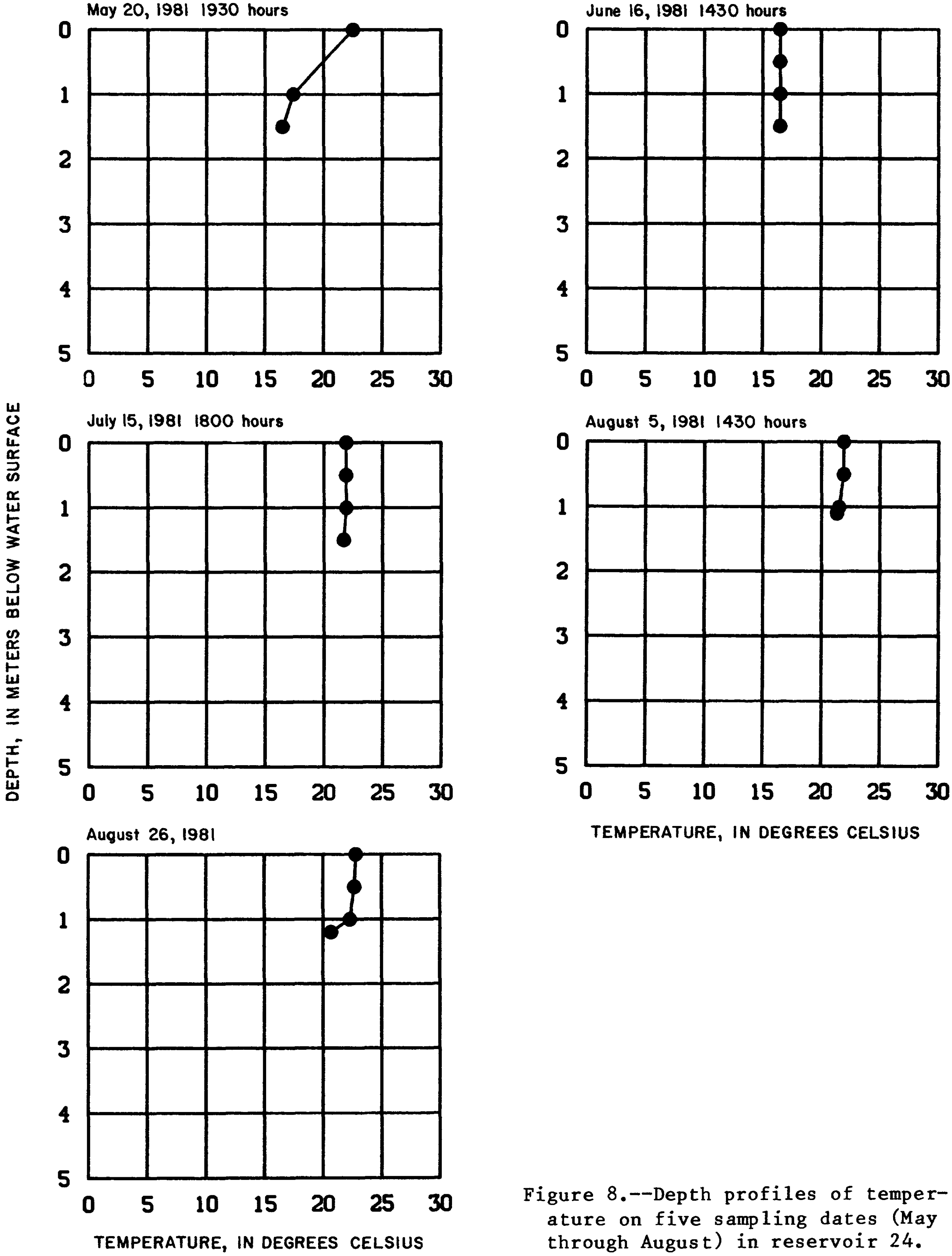


Figure 8.--Depth profiles of temperature on five sampling dates (May through August) in reservoir 24.

Dissolved oxygen

Dissolved-oxygen concentrations measured during daylight (figs. 9-12) ranged from 0.3 mg/L (milligram per liter) in the near-bottom water of reservoir 19 during late August to 13.4 mg/L in the near-surface water of reservoir 19 during early August. With the exception of reservoir 9, the largest dissolved-oxygen concentration in the near-surface water of each reservoir was measured during either early or late August. In reservoir 9, dissolved-oxygen concentrations were largest in May and June possibly because of increased production by a well-established macrophyte population in response to the influx of nutrients from spring runoff.

Dissolved-oxygen gradients existed in all reservoirs; the dissolved-oxygen concentrations generally were maximum and larger than saturation near the surface, and minimum and smaller than saturation near the bottom. The largest differences in dissolved-oxygen concentrations between near-surface and near-bottom water in each reservoir generally occurred during either early or late August sampling.

Reservoir 9 generally had the smallest dissolved-oxygen concentration differential during each sampling and maintained larger dissolved-oxygen concentrations in the near-bottom water than reservoirs 1, 19, and 24. The large oxygen concentrations in the near-bottom water of reservoir 9 probably resulted in part from photosynthesis by macrophytes and attached algae that were growing across the entire reservoir bottom. In contrast, reservoirs 1 and 19 generally had the largest differences in dissolved-oxygen concentration from near-surface to near-bottom water and the smallest dissolved-oxygen concentration in the near-bottom water. The decomposition of black organic muds observed in the bottom sediments of reservoirs 1 and 19 most likely contributed to decreased concentrations of dissolved oxygen.

The dissolved-oxygen gradient between the near-surface and near-bottom water mainly is a result of photosynthesis by aquatic plants in the euphotic zone and respiration and decomposition of aquatic plants and animals in the sediment. Because of dissolved-oxygen consumption by decomposition and respiration in the near-bottom water coupled with little replacement by photosynthesis, near-bottom water generally has less dissolved oxygen than near-surface water.

The shallowness of the reservoirs helps prevent the development of anoxic conditions that would limit their usefulness. Periodic mixing during the summer replenishes dissolved oxygen that is consumed by decomposition in the bottom water. If stratification occurred in these reservoirs at higher reservoir stages during wet years, the near-bottom water could possibly become anaerobic by late summer. The possibility of this condition is indicated by an increase in the difference of dissolved-oxygen concentrations between near-surface and near-bottom water from May to August. By preventing anaerobic conditions in the near-bottom water, mixing could moderate water-quality changes in other constituents such as trace elements, that otherwise would occur as uncirculating near-bottom water formed a reducing environment capable of bringing trace elements into solution. Conversely, mixing throughout the entire depth of the reservoir may recirculate nutrients deposited in the bottom sediments. Circulation could increase plant production and lead to potential dieoffs, with subsequent oxygen consumption. These contrasting physical processes could lead to fluctuating dissolved-oxygen concentrations throughout the summer.

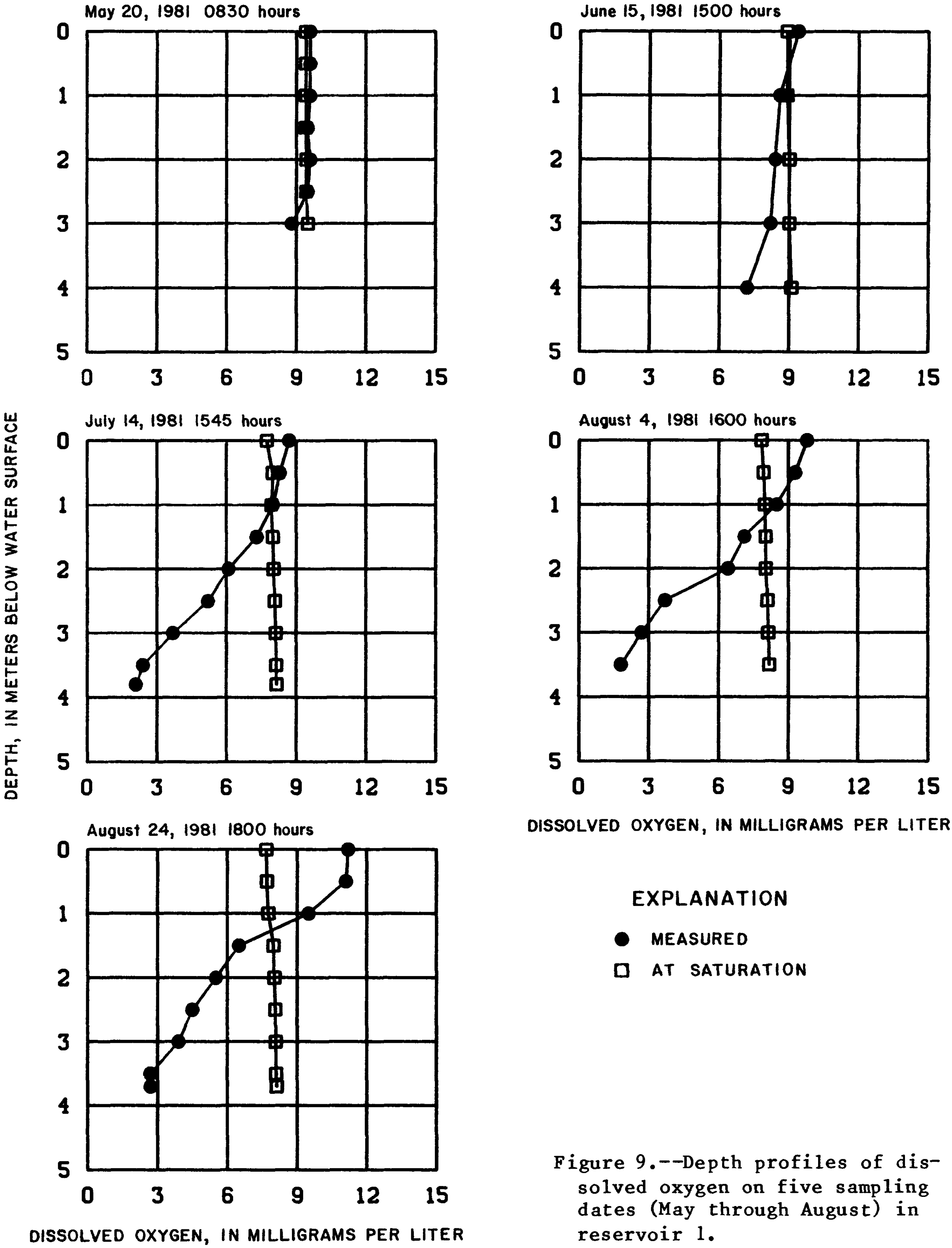


Figure 9.--Depth profiles of dissolved oxygen on five sampling dates (May through August) in reservoir 1.

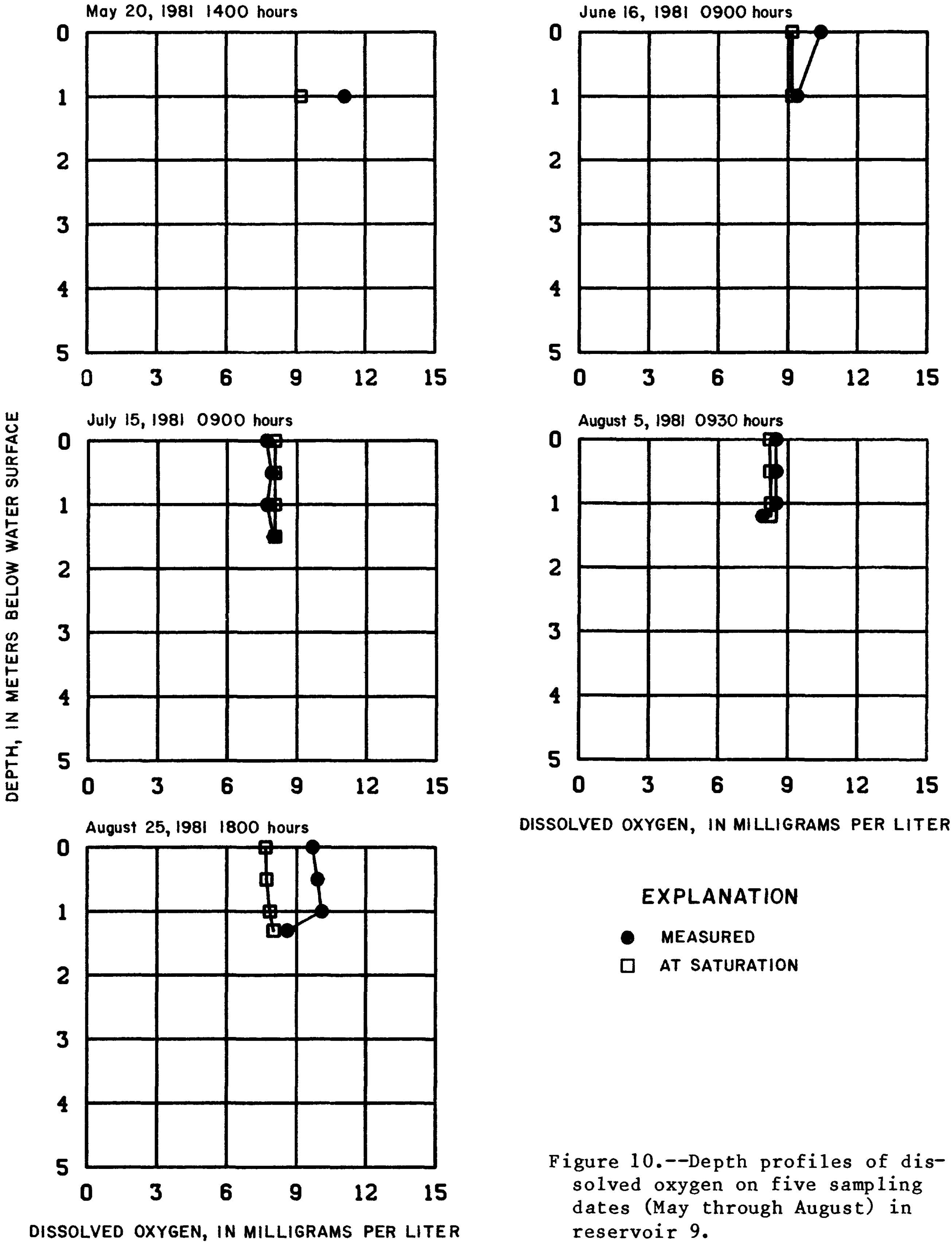


Figure 10.--Depth profiles of dissolved oxygen on five sampling dates (May through August) in reservoir 9.

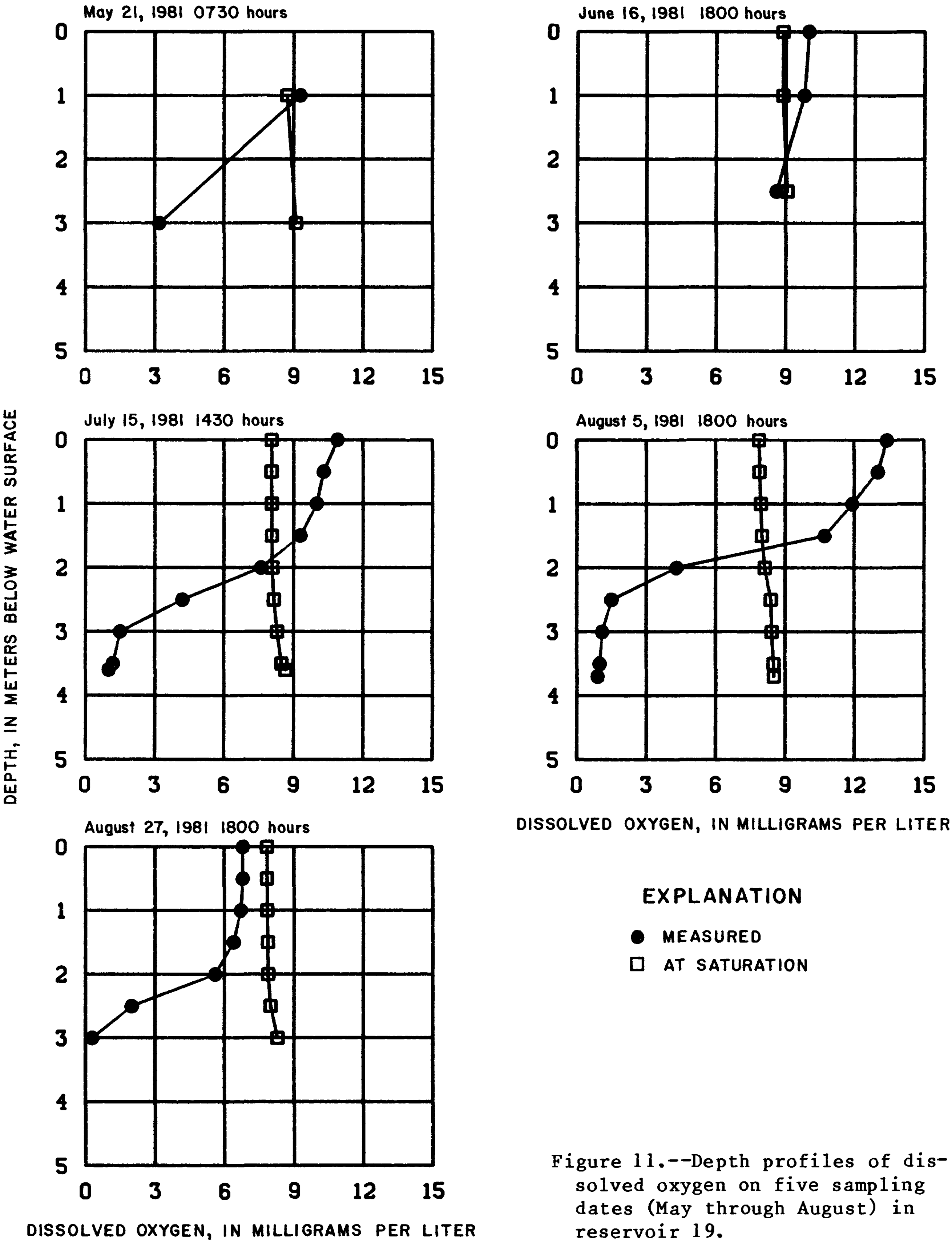


Figure 11.--Depth profiles of dissolved oxygen on five sampling dates (May through August) in reservoir 19.

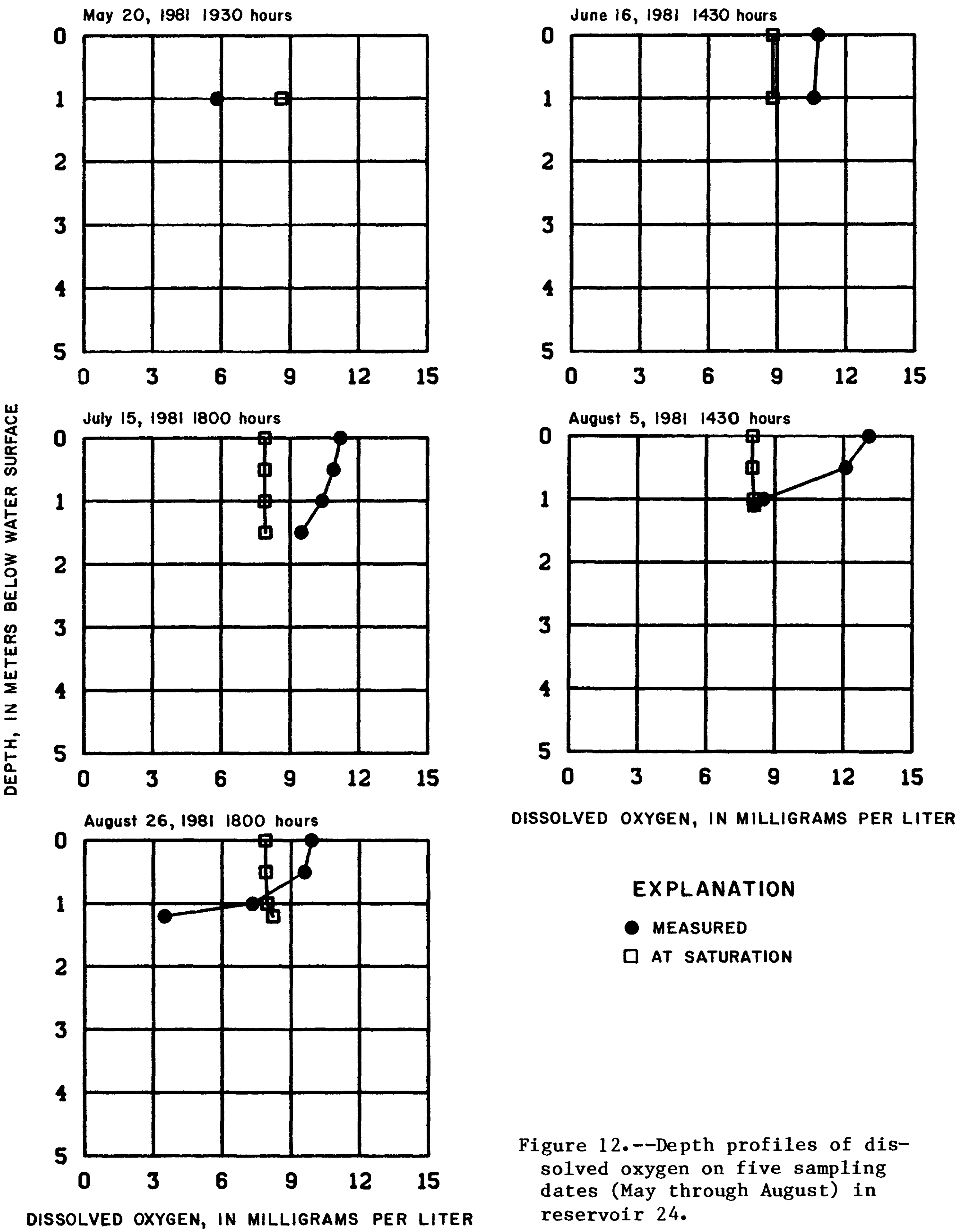


Figure 12.--Depth profiles of dissolved oxygen on five sampling dates (May through August) in reservoir 24.

pH

Values of pH in the near-surface water of the study reservoirs (figs. 13-16) ranged from 8.1 in reservoir 24 in June to 9.8 in reservoir 9 in late August. Reservoirs 1 and 9 generally had larger pH values than reservoirs 19 and 24. The smallest pH, 7.9, occurred in the near-bottom water of reservoir 19 in May.

In May, June, and July, pH values generally were homogeneous with depth in reservoirs 1, 9, and 24, whereas values decreased with depth in reservoir 19. In these months, the pH differences between the near-surface and near-bottom waters in reservoir 19 ranged from 0.2 to 0.8 standard unit. In each reservoir the largest pH gradients usually occurred in August. At this time the pH differences between the near-surface and near-bottom water for reservoir 19 were the largest among the reservoirs, ranging from 0.7 to 0.9 standard unit.

A byproduct of respiration and decomposition is CO_2 (carbon dioxide), which on entering the water decreases the pH. During photosynthesis CO_2 dissolved in water is utilized, thereby increasing the pH during the day. Differences in pH between the near-surface and near-bottom water in the study reservoirs most likely result from photosynthesis, respiration, and decomposition in a manner similar to that of dissolved oxygen.

Of the four proposed reservoir uses, recreational swimming would be limited in all the study reservoirs because of measured pH values greater than the recommended maximum of 8.3 (National Technical Advisory Committee to the Secretary of the Interior, 1968). During August in reservoir 9, fish propagation, waterfowl habitat, and livestock watering might be affected adversely by pH at or near recommended values--9.0 for fish and livestock (U.S. Environmental Protection Agency, 1978) and 9.2 for waterfowl (National Technical Advisory Committee to the Secretary of the Interior, 1968).

Specific conductance

The reservoirs represent a considerable range of specific conductance (figs. 17-20). Reservoir 24 had the smallest specific-conductance values, which ranged from 192 to 308 μS/cm (microsiemens per centimeter at 25° Celsius). Reservoir 9 had the largest specific-conductance values, which ranged from 3,500 to 4,610 μS/cm.

Minimal specific-conductance gradients consisting of a slight increase near the bottom were determined in each reservoir. However, middepth maximum specific-conductance values were measured in reservoir 1 during the July and August sampling and in reservoir 9 during the May sampling.

The differences in specific conductance among the study reservoirs are related to differences in local mineralogy and the effect of varying hydrologic factors. Mineralogy differences are discussed in the section of this report titled "Chemical analyses, major dissolved constituents."

Ground-water flow, surface-water flow, evaporation, transpiration, and precipitation control the net volume of water in each reservoir. Surface-water inflow and evaporation are major factors that cause seasonal changes in specific conductance by changing the concentration of dissolved solids. Probably because of water

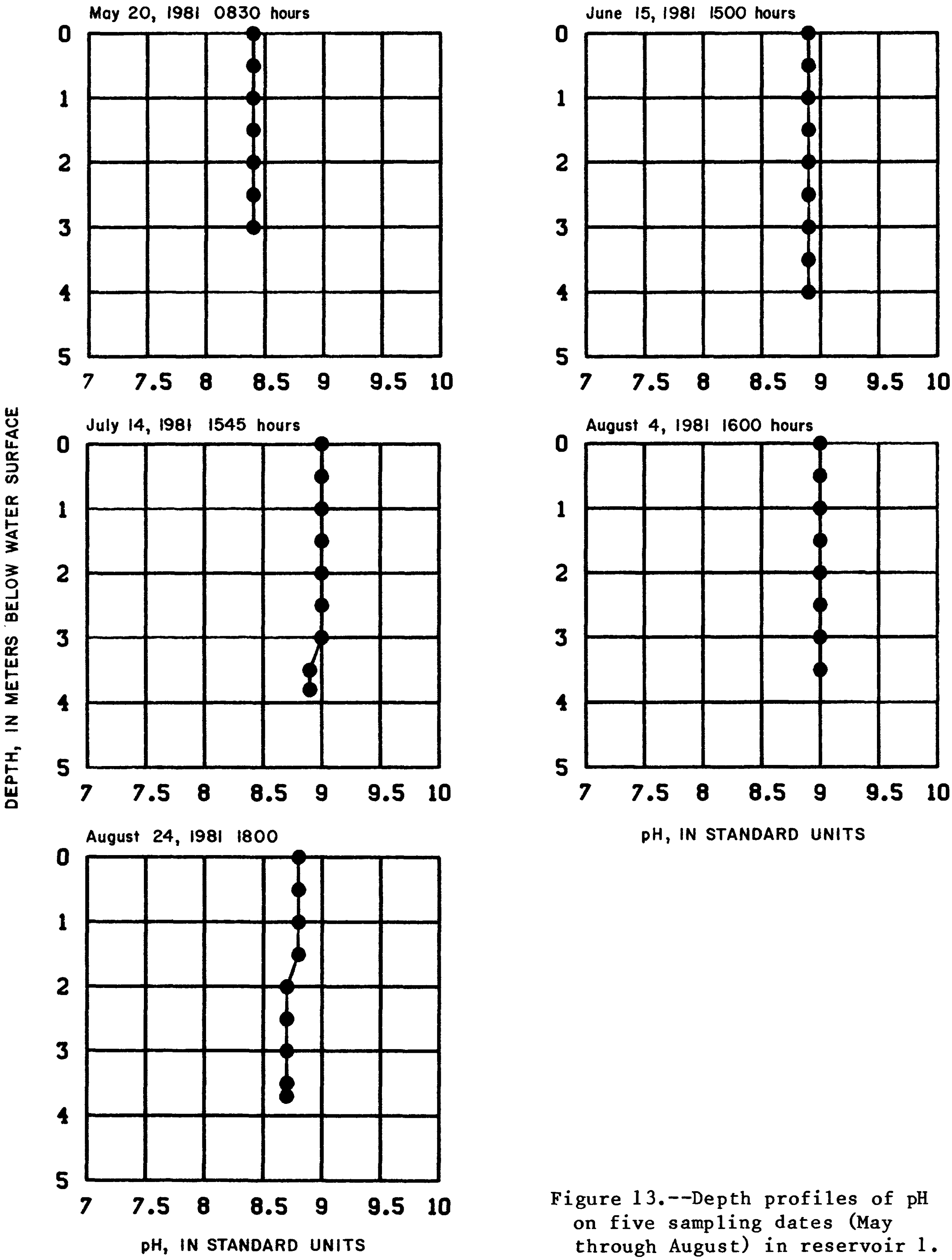


Figure 13.--Depth profiles of pH on five sampling dates (May through August) in reservoir 1.

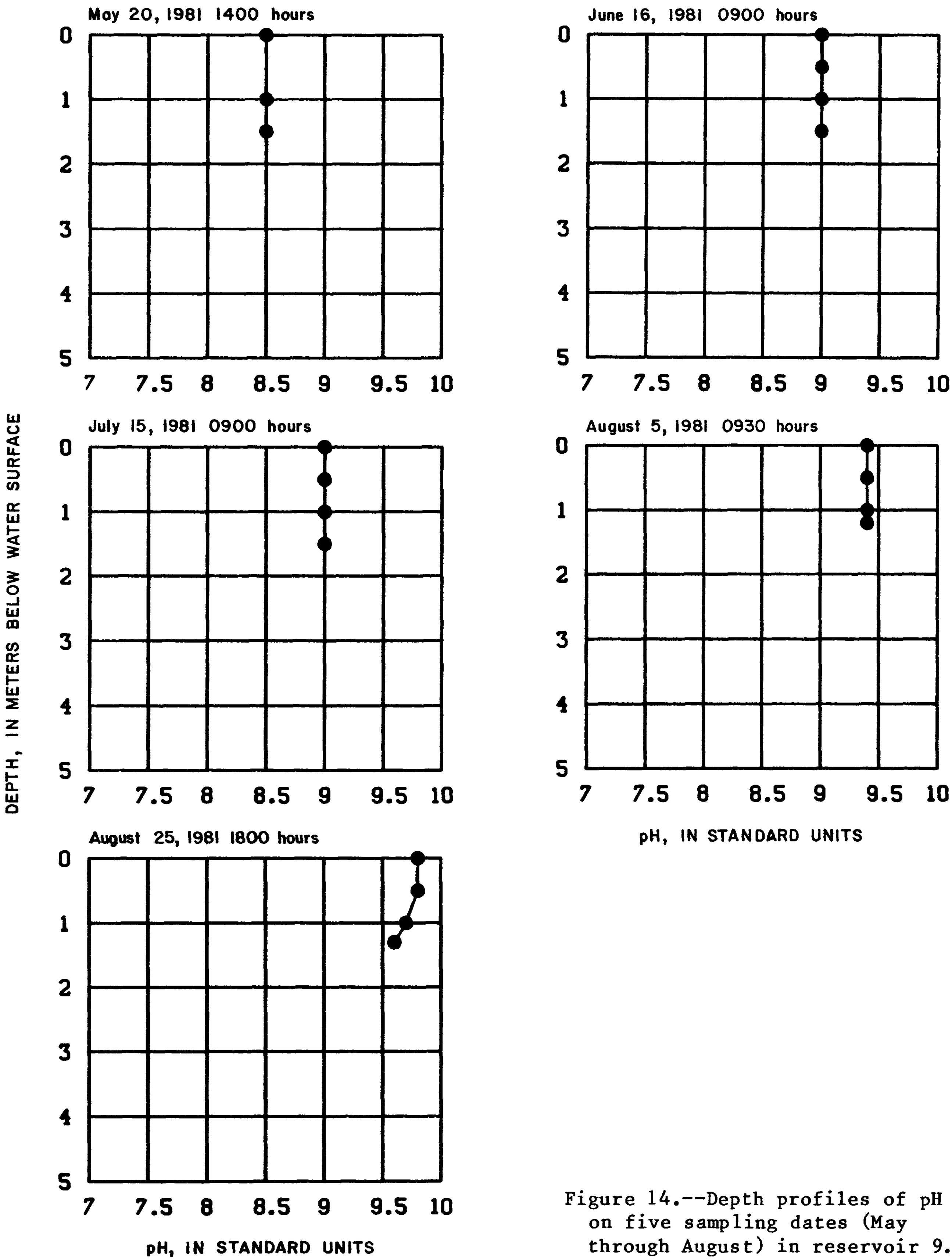


Figure 14.--Depth profiles of pH on five sampling dates (May through August) in reservoir 9.

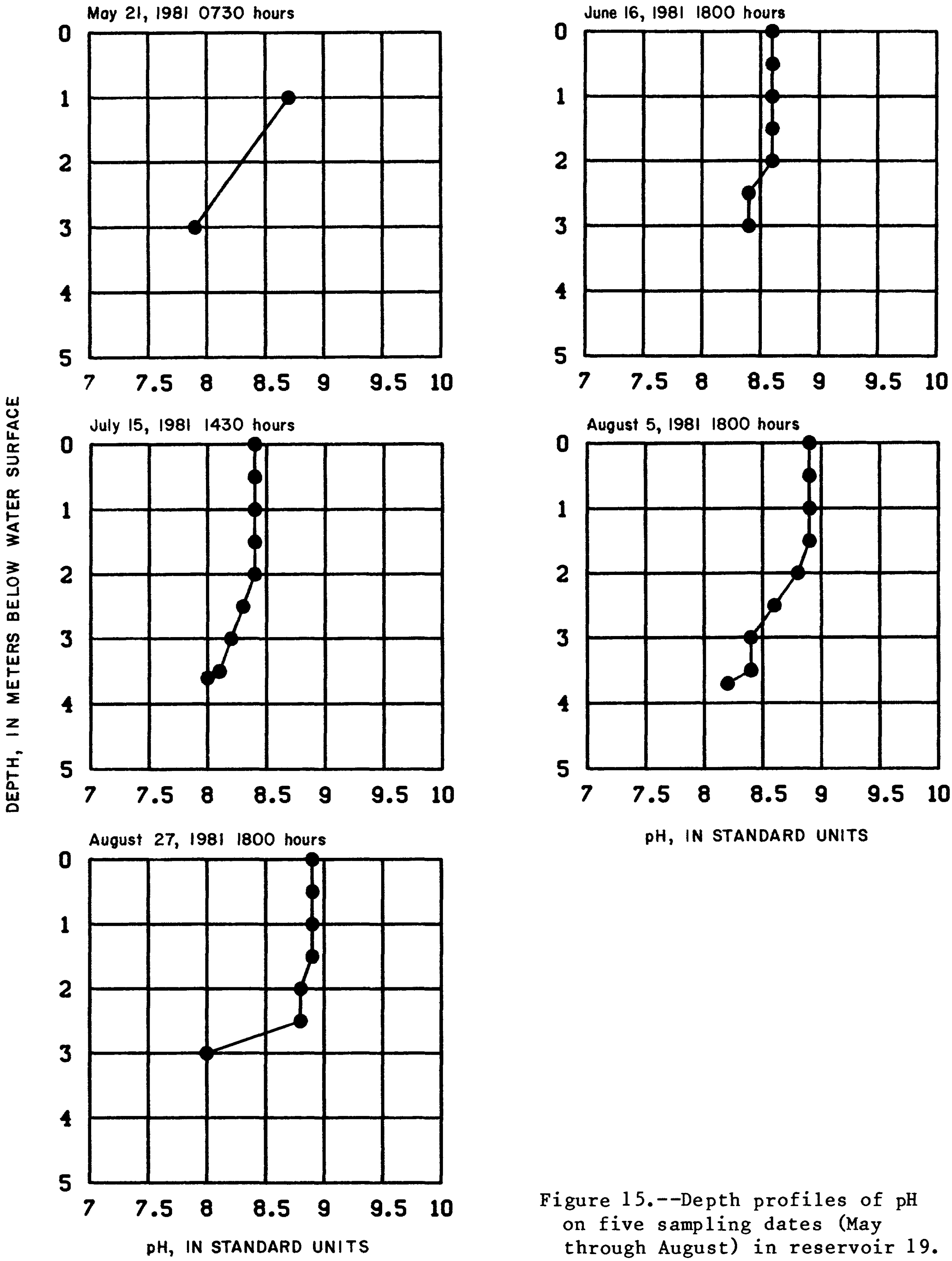


Figure 15.--Depth profiles of pH on five sampling dates (May through August) in reservoir 19.

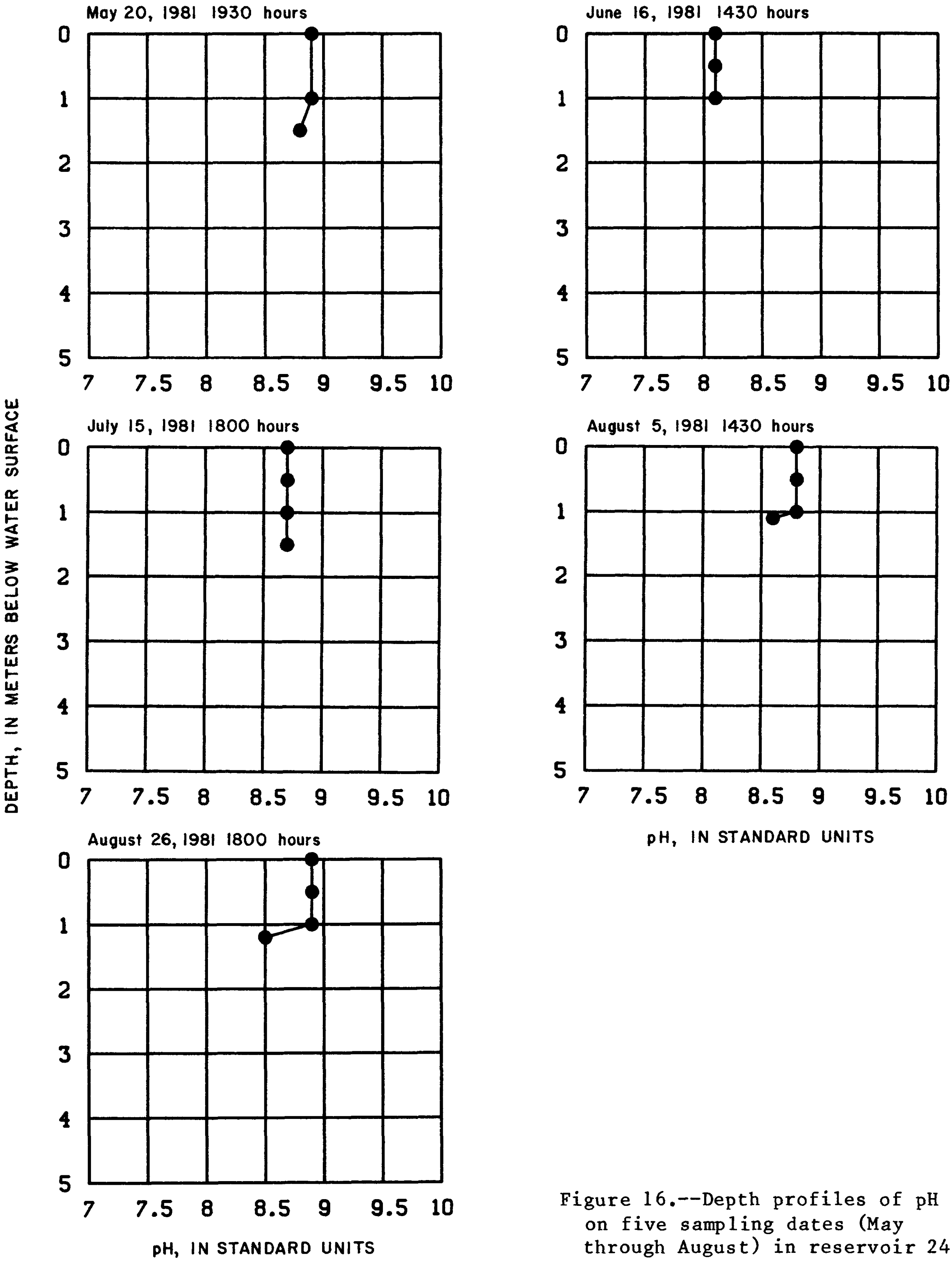


Figure 16.--Depth profiles of pH on five sampling dates (May through August) in reservoir 24.

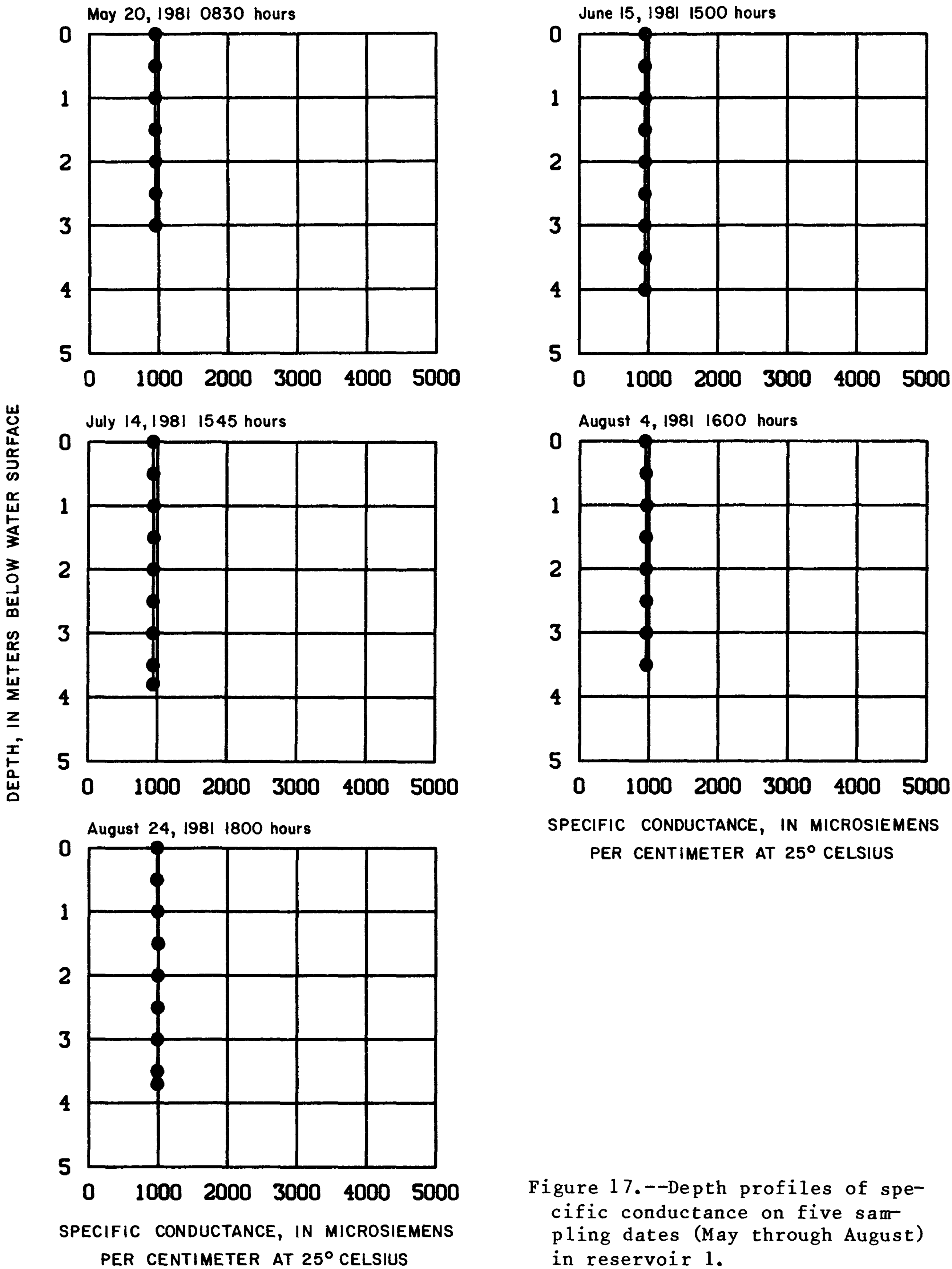


Figure 17.--Depth profiles of specific conductance on five sampling dates (May through August) in reservoir 1.

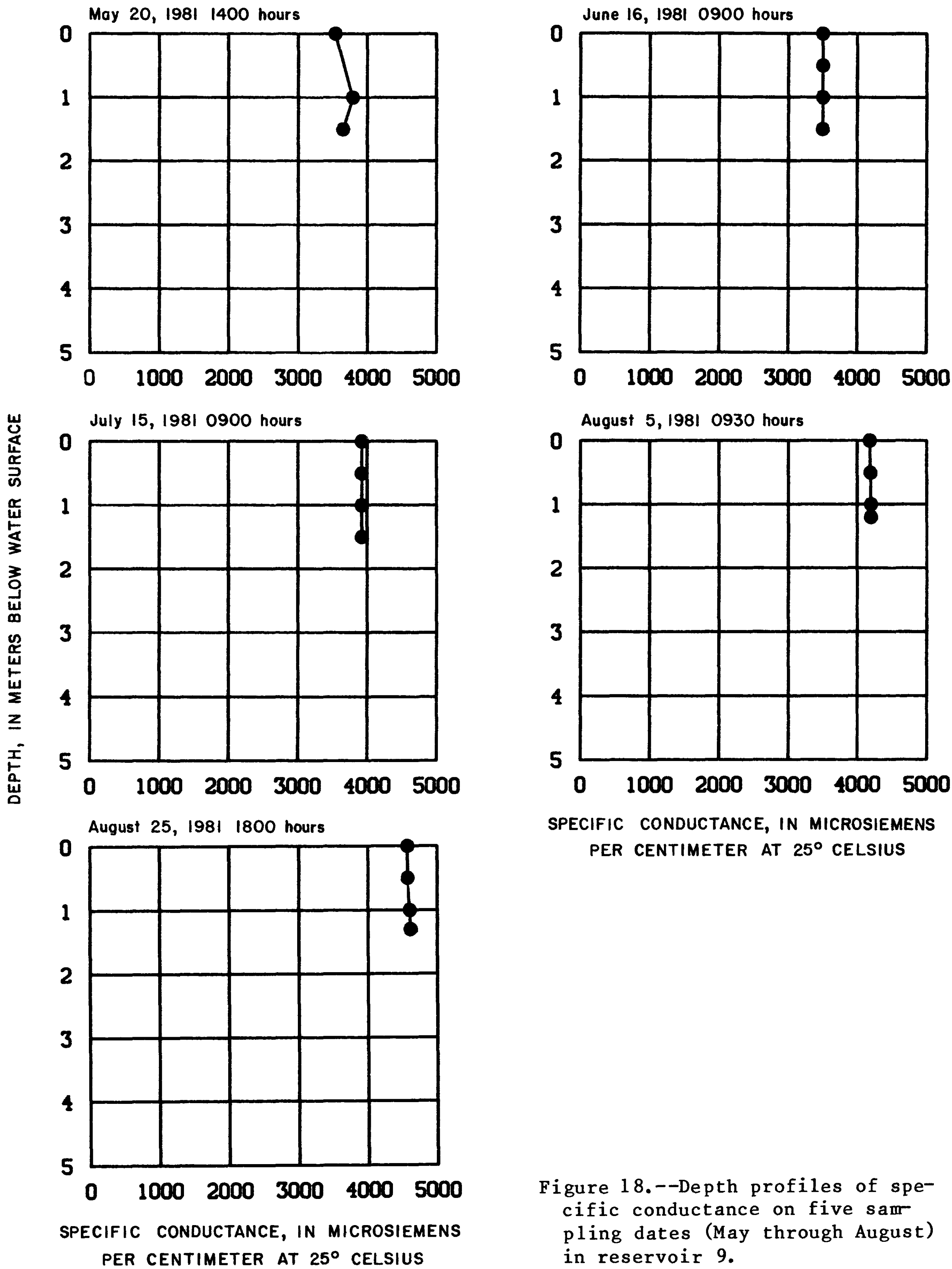


Figure 18.--Depth profiles of specific conductance on five sampling dates (May through August) in reservoir 9.

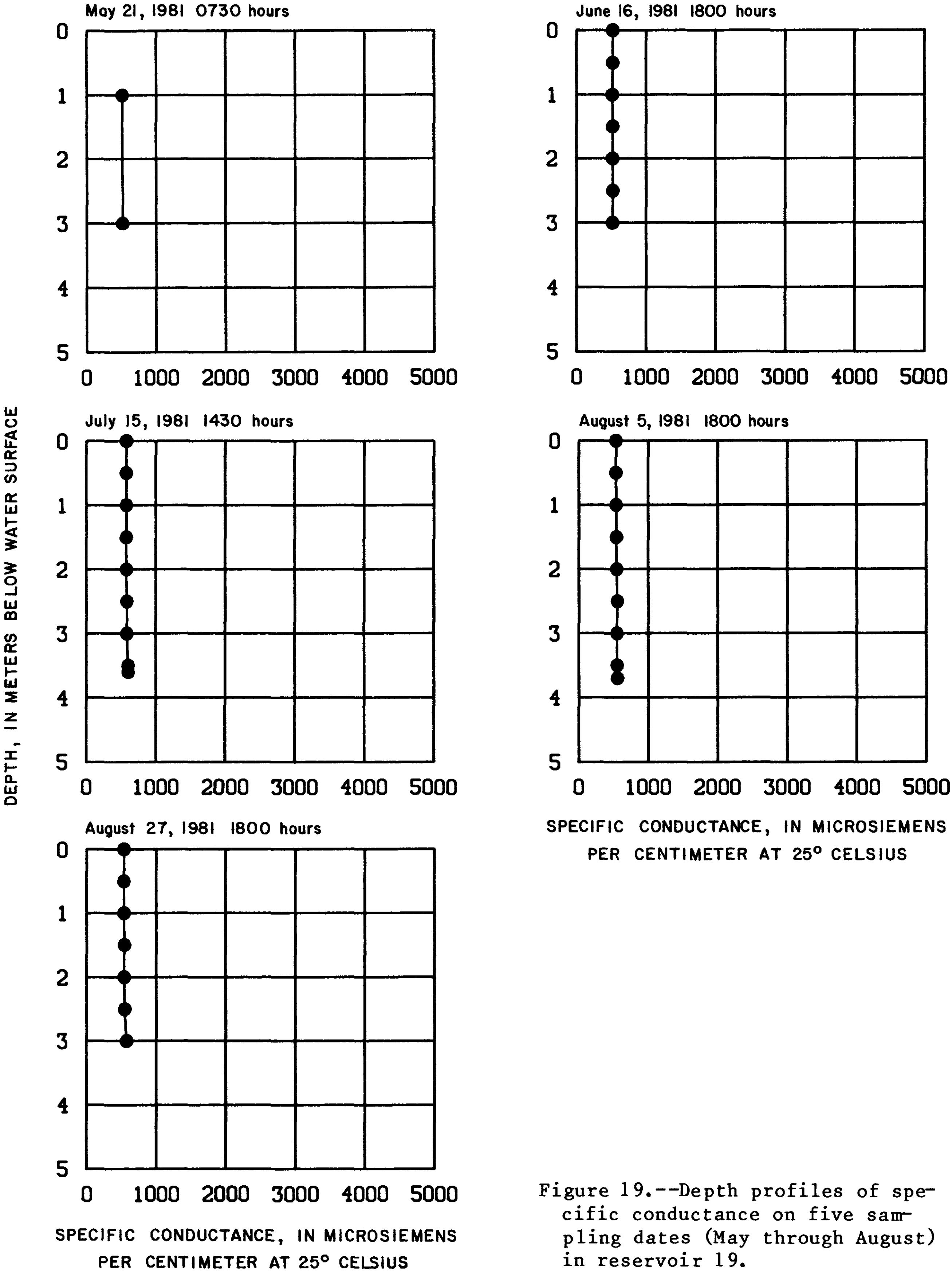


Figure 19.--Depth profiles of specific conductance on five sampling dates (May through August) in reservoir 19.

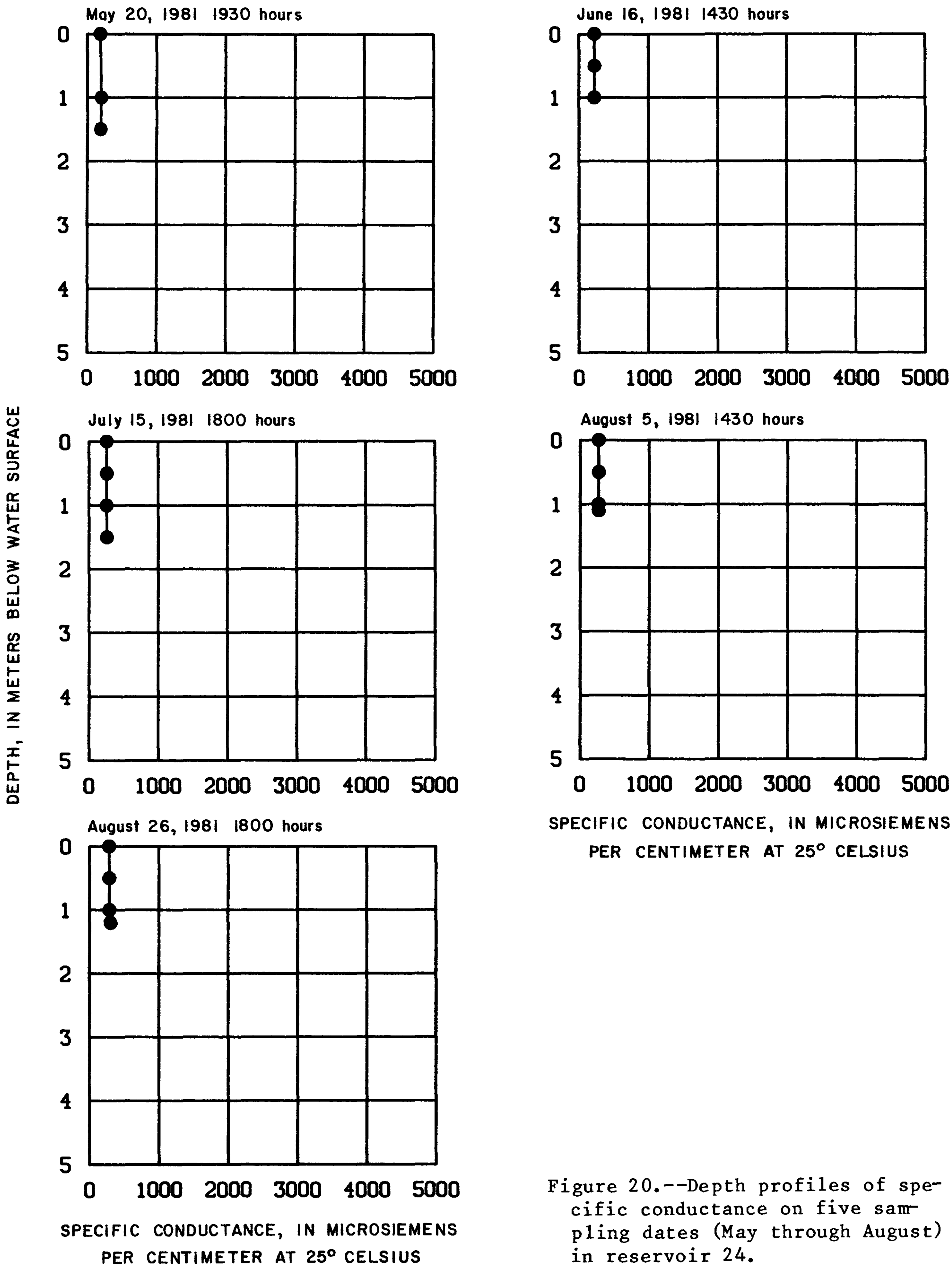


Figure 20.--Depth profiles of specific conductance on five sampling dates (May through August) in reservoir 24.

loss with evaporation and transpiration, dissolved-solids concentrations generally increase from May to August. Among the reservoirs, the occurrence of minimum specific conductances during times other than May can be related to the occurrence of summer precipitation. Given a relatively large drainage area, summer precipitation could provide sufficient surface-water inflow to dilute the dissolved-solids concentration. About 38.1 mm of precipitation a few days prior to sampling reservoir 9 in June and reservoir 1 in July most likely was the cause of minimum specific conductances after May.

Light penetration

The small percentage of surface light penetration and the shallow Secchi-disk depth both indicate that reservoirs 19 and 24 are more turbid than reservoirs 1 and 9 (fig. 21). The greatest light penetration was observed in reservoir 1 where two Secchi-disk depths were greater than 1.5 m and light sufficient for photosynthesis and probably net primary production (greater than 1 percent of the incident light) occurred near the bottom. Although reservoir 9 did not have the clarity of reservoir 1, sufficient light for photosynthesis also reached the bottom because of the shallow depths of the reservoir. Reservoir 9 had macrophytes (aquatic plants) rooted across the lake bottom.

Reservoir 1 showed a gradual increase in percentage of light transmission and Secchi-disk depth from May to July. In reservoir 9 there was an abrupt increase in percentage of light transmission and Secchi-disk depth from May to June. Compared to May, June, and July, the August percentage of surface light in reservoir 9 showed a more linear decrease with depth. However, the Secchi-disk depths in reservoir 9 were variable during the study. Light penetration and Secchi-disk depths in reservoirs 19 and 24 remained about the same during the study.

Seasonal changes in light penetration among the reservoirs are affected by a combination of factors, including concentration of suspended materials transported by spring runoff, seasonal phytoplankton succession, shoreline disturbance by cattle, and wind-induced mixing of the reservoir, which resuspends bottom sediments. The greater light penetration in reservoirs 1 and 9 could be the result of wind protection afforded by adjacent hills. Reservoirs 19 and 24 are in relatively open areas and, therefore, are subject to more frequent wind mixing. Reservoirs 1 and 9 also contained smaller phytoplankton concentrations than reservoirs 19 and 24, which would allow greater light penetration (see Biological analyses, Phytoplankton).

Chemical analyses

Major dissolved constituents

Relative concentrations of the major dissolved constituents indicate that reservoirs 1 and 24 have sodium bicarbonate water, reservoir 9 has sodium sulfate water, and reservoir 19 has sodium bicarbonate sulfate water (table 4; Supplemental Information section at back of report). Reservoir 9 had the largest dissolved-solids concentrations (2,900-3,790 mg/L) and reservoir 24 had the smallest (123-162 mg/L). No consistent monthly trend occurred at each reservoir for each major dissolved constituent; however, the dissolved-solids concentration (summation of all constituents with a correction for CO_2 loss) increased slightly from May to August.

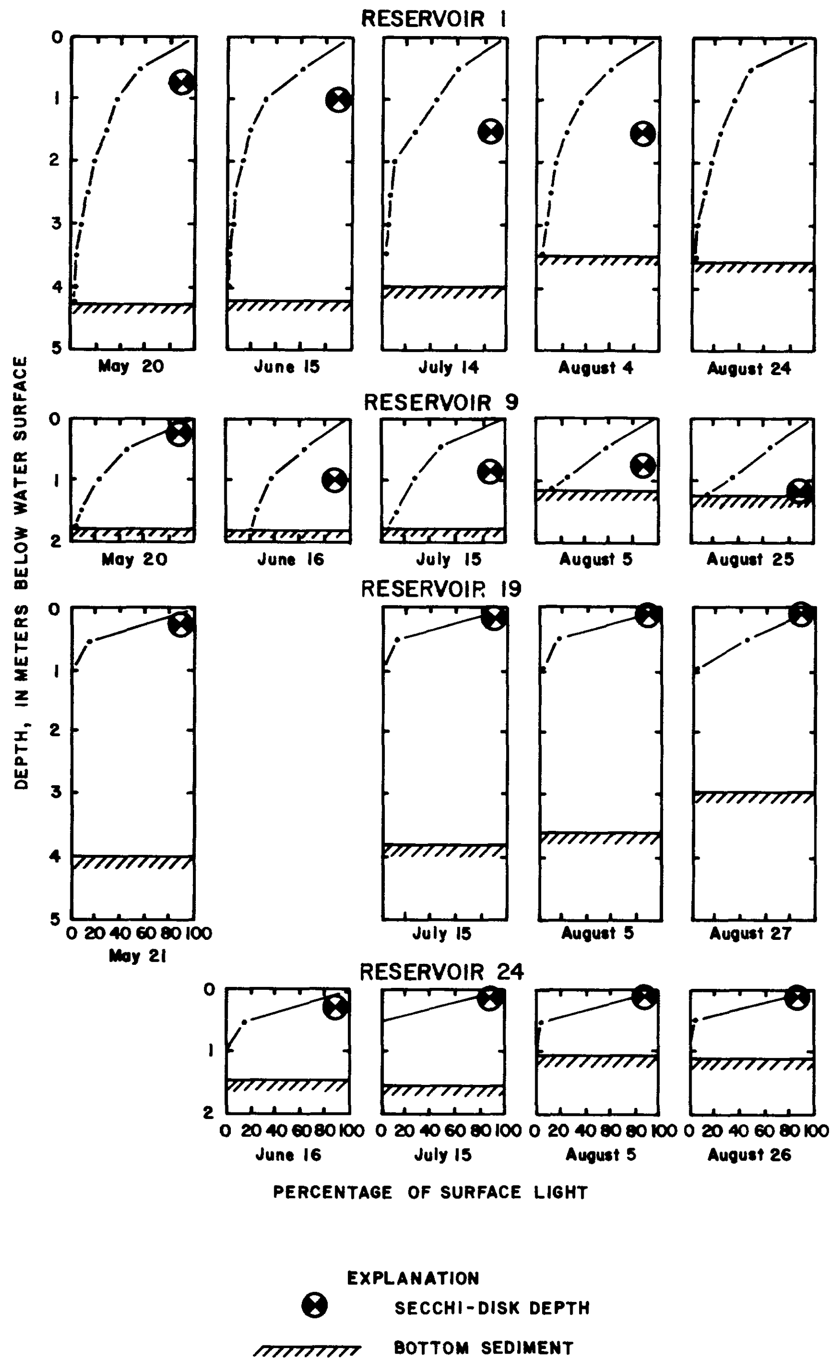


Figure 21.--Relationship of depth to percentage of surface light and Secchi-disk depth in reservoirs 1, 9, 19, and 24 on five or less sampling dates (May through August).

Although several hydrologic factors function in combination with local mineralogy to produce the major dissolved constituents present during any given time, local mineralogy of the drainages for each reservoir is indicated to be a principal factor affecting the composition of constituents. The reservoirs are regionally close to one another, but only drainages of reservoirs 19 and 24 are located entirely within the area of the Bearpaw Shale. Both of these reservoirs had small dissolved-solids concentrations compared to reservoirs 1 and 9. However, the differences in water quality as a result of local mineralogy is indicated by the smaller dissolved-solids concentration (smaller specific conductance) and the sodium bicarbonate type water in reservoir 24 compared to the larger dissolved-solids concentration (larger specific conductance) and the sodium bicarbonate sulfate water in reservoir 19.

Continued leaching of major dissolved constituents from the drainage and subsequent concentrating of major dissolved constituents with evaporation are expected to increase dissolved-solids concentrations as reservoirs age. Yet, the results of samples from the reservoirs do not indicate that age is a principal factor in determining the relative concentration of dissolved constituents. For example, reservoir 9 had the largest dissolved-solids concentration even though it is the newest reservoir and reservoir 19 had the second smallest dissolved-solids concentration even though it is the oldest reservoir. Within each reservoir, dissolved-solids concentration could increase with age as indicated by the smaller dissolved-solids concentrations that were measured in 1978 and 1979 (Ferreira, 1980; 1983). However, these differences are affected by the volume of water gain or loss and commensurate diluting or concentrating that occurred prior to sampling.

The percentage increase in dissolved constituents from May to August due to evaporative water losses is affected by the ratio of the reservoir's volume to surface area. For a given volume, those reservoirs having larger surface area (shallow) would have a larger percentage loss of total volume of water for a given evaporation rate. Reservoirs 9 and 24, being relatively shallow compared to reservoirs 1 and 19, had a larger percentage increase in dissolved-solids concentration. The greater depths of reservoirs 1 and 19 resulted in a smaller percentage of water loss and, consequently, a smaller percentage increase in dissolved-solids concentration. Percentage increases in dissolved-solids concentration from May to August ranged from about 1 percent in reservoir 1 to 29 percent in reservoir 9.

Reservoirs 1 and 19 each were sampled at two depths. Both reservoirs showed slight differences in dissolved-solids concentration between the near-surface and near-bottom water samples. The slight increases in dissolved-solids concentration determined in most samples of near-bottom water of the reservoirs could originate from dissolution of material in the bottom sediments.

Nutrients

Total nitrogen concentrations ranged from 1.4 mg/L in reservoirs 1 and 9 to 7.5 mg/L in reservoir 24 (table 5; Supplemental Information section at back of report). In reservoirs 19 and 24, total nitrogen concentrations were smaller in May and June than in July and August. In reservoirs 1 and 9, total nitrogen was variable from May to August, although both had maximum concentrations in early August. In reservoirs 1 and 19, differences in total nitrogen concentrations between the near-surface and near-bottom water were slight. Because total nitrogen is composed mostly of total organic nitrogen in these reservoirs, observed trends are a reflection of trends in total organic nitrogen. Ammonia also showed trends similar to total nitrogen.

Increases of nitrogen concentrations in the reservoirs from May to August could result from the concentrating effect of evaporative water loss, continued input of nitrogen from decomposition in the bottom sediments, and external inputs from activities close to each reservoir such as grazing livestock. In addition, increases could result from nitrogen fixation by blue-green algae. Decreases can occur because of nitrogen uptake by aquatic plants or the settling of sediment to which nitrogen has sorbed. The variation in total nitrogen probably is due to a combination of all the above factors, of which the relative concentration of each can be different for each reservoir.

Reservoir 9 had the smallest total phosphorus concentrations (<0.01-0.10 mg/L, table 5). Reservoir 24 had the largest total phosphorus concentrations (<0.01-0.34 mg/L). Dissolved orthophosphorus concentrations were similar among all the reservoirs, except for larger concentrations in reservoir 1 during August.

Phosphorus can be derived from many of the same sources as nitrogen, but trends in phosphorus concentrations were not always similar to those of nitrogen. Only reservoir 1 had an increase of phosphorus from May to August. Reservoir 9 had the largest total phosphorus concentration occurring in May, presumably from spring runoff. Measured concentrations of nitrogen (total nitrogen greater than 1.1 mg/L N) and phosphorus (total phosphorus greater than 0.03 mg/L P) indicate that the reservoirs are enriched with nutrients (Ferreira, 1983).

Whether nitrogen or phosphorus is limiting phytoplankton growth can be indicated by comparing the concentrations of inorganic nitrogen (NO_2 + NO_3 plus ammonia) to orthophosphorus. If inorganic nitrogen is more than 10 times the orthophosphorus concentration, then phosphorus generally is limiting. If inorganic nitrogen is less than five times the orthophosphorus concentration, then nitrogen commonly is limiting (Zison and others, 1977).

Generally, nutrient ratios are calculated using dissolved concentrations, because these forms are readily available for plant uptake. Because dissolved ammonia concentrations were not available, the ratios in this study were calculated with total concentrations of inorganic nitrogen and dissolved concentrations of orthophosphorus to indicate what the limiting nutrients might be. The dissolved and total concentrations of NO_2 + NO_3 were similar in samples collected during this study. However, nutrient samples collected in previous studies (Ferreira, 1980, 1983) indicate that the total ammonia concentration is more variable, ranging from being equal to being greater than the dissolved ammonia concentration. Therefore, when the ratio indicates nitrogen is the limiting nutrient ($N/P < 5$), using dissolved values of nitrogen will not change the interpretation. However, when the ratio indicates phosphorus is the limiting nutrient ($N/P > 10$), the interpretation may be questionable owing to the possibility of total ammonia concentration being considerably larger than that of dissolved ammonia. But, because nitrogen is not as strongly sorbed to sediment as phosphorus (total forms), total ammonia can be considered available for plant uptake. Therefore, the ratios calculated from total nitrogen concentrations are useful as a general indication of nutrient availability in the study reservoirs.

Based on nitrogen and phosphorus ratios, all the reservoirs were phosphorus limited in May but became nitrogen limited in June. In July all the reservoirs remained nitrogen limited except reservoir 19, which again became phosphorus limited. In August only reservoir 1 remained nitrogen limited; the other reservoirs were phosphorus limited. Changes in the role of limiting nutrients probably occur because of the uptake and release of nutrients by fluctuating phytoplankton populations and sorption and desorption by sediments resuspended during mixing.

Relative differences among the reservoirs in total organic-carbon concentrations are similar to the relative differences for total phosphorus (table 5). Because the production of organic matter is in part dependent upon the availability of phosphorus, and the supply of carbon from atmospheric CO_2 is unlimited, relative differences in organic carbon among the reservoirs would be the same as phosphorus in the absence of major external sources. In general, the quantity of total organic carbon in the reservoirs is proportional to the number of planktonic organisms in each reservoir.

Reservoirs tend to progress through stages of increased nutrient enrichment with age. As productivity rates increase with nutrient supply, the suitability of a reservoir for different uses can change. Although nutrient concentrations in each reservoir probably are increasing with reservoir age, the variable concentrations of nutrients observed among the reservoirs of different ages do not show this relationship. Therefore, nutrient concentrations are more affected by local differences in mineralogy and land use than by aging of the study reservoirs.

Trace elements

Of all the trace elements analyzed for, manganese was present in the largest concentrations (table 6; Supplemental Information section at back of report); reservoirs 19 and 24 generally had the largest concentrations of total recoverable manganese among the study reservoirs. Total recoverable lead occurred in large concentrations in reservoirs 19 and 24, but only in late August. Dissolved iron had the second largest concentrations among the trace elements; the largest concentrations occurred in reservoirs 9 and 24. Differences in trace-element concentrations are most likely caused by differences in local mineralogy.

In reservoirs 1, 19, and 24 the concentration of total recoverable manganese generally increased from May to August. In reservoir 9 total recoverable and dissolved manganese decreased from May to August. The only other consistent patterns among the trace elements were decreases in dissolved iron and manganese in reservoir 24 from May to August.

During each sampling, the near-bottom water in reservoirs 1 and 19 generally had larger trace-element concentrations than the near-surface water. Seasonal changes in the concentrations of trace elements are related to the concentrating effect of water loss through evaporation and changes in trace-element equilibria caused by biological processes. In late August, total recoverable lead in reservoirs 19 and 24 exceeded by the greatest degree the concentration recommended by the U.S. Environmental Protection Agency (1980) for the protection of fish (9.9 μg/L at a hardness as calcium carbonate of 150 mg/L).

Biological analyses

Phytoplankton

Except for reservoir 9 in late August and reservoir 24 in May, Chlorophyta (green algae) was either dominant or codominant (equal to or greater than 15 percent) in all reservoirs during each sampling (table 7; Supplemental Information section at back of report). Cyanophyta (blue-green algae) generally was either dominant or codominant in May and August in all the reservoirs except reservoir 1. Concentrations of Cyanophyta were not detected as being dominant in reservoir 1 during the study. Cryptophyta (cryptomonads) was codominant in July or August in reservoirs 1, 9, and 19 and codominant in May in reservior 24. Bacillariophyta (includes diatoms) was dominant or codominant in late August in reservoir 1, in July in reservoir 9, in June in reservoir 19 and in May, June, and late August in reservoir 24. Euglenophyta (euglenoids) were dominant or codominant in May in reservoir 9 and in late August in reservoir 24.

The numbers and types of phytoplankton differ from one body of water to another; no truly "typical" community exists (Reid and Wood, 1976). The community composition of phytoplankton involves complex interactions by many factors such as nutrient loading, reservoir mixing, water type, temperature change, light availability, physiology and reproductive rate of the phytoplankton, and harvest rate by zooplankton. Therefore, similar types of phytoplankton occurring in different proportions in each of the study reservoirs is expected. Green algae, blue-green algae, and flagellates (which include cryptomonads) collected from the study reservoirs are characteristically abundant in warm, nutrient-enriched water, as opposed to cold, nutrient-deficient water in which diatoms generally are most abundant.

Because of the ability of blue-green algae to fix elemental nitrogen, they typically have late summer growth that exceeds other groups of algae as inorganic nitrogen (NO_2 + NO_3 plus ammonia) becomes depleted. This late summer growth could account, in part, for the dominance or codominance of blue-green algae in the study reservoirs. However, other factors probably are interacting with phytoplankton, because blue-green algae were not always dominant or codominant during June and July when nitrogen is indicated to be limiting. In reservoir 1, which was indicated to be nitrogen limited all months except May, blue-green algae were never detected as being dominant.

Phytoplankton cell concentrations (fig. 22) at a depth of 1 m were largest in reservoir 24 and smallest in reservoirs 1 and 9. The large phytoplankton cell concentrations in reservoir 24 correspond to large nutrient concentrations (tables 5 and 7). The smaller phytoplankton cell concentrations in reservoirs 1 and 9 correspond to smaller nutrient concentrations in these reservoirs. Although reservoirs 1 and 9 are indicated to be mesotrophic by their phytoplankton cell concentrations (between 1,000 and 15,000 cells per mL; Taylor and others, 1980), they both support large growths of macrophytes. Sampling during other years or at other times might indicate larger concentrations of phytoplankton than determined during this study.

Throughout the season, the abundance of major groups of phytoplankton varies in response to environmental changes. Generally for temperate lakes, two pulses of phytoplankton growths occur during the year: one in early spring in response to an influx of nutrients with runoff, and one in late summer as the water becomes warmer and metabolic rates of the plants increase (Reid and Wood, 1976). A spring pulse in phytoplankton concentration in the study reservoirs was not evident. For the

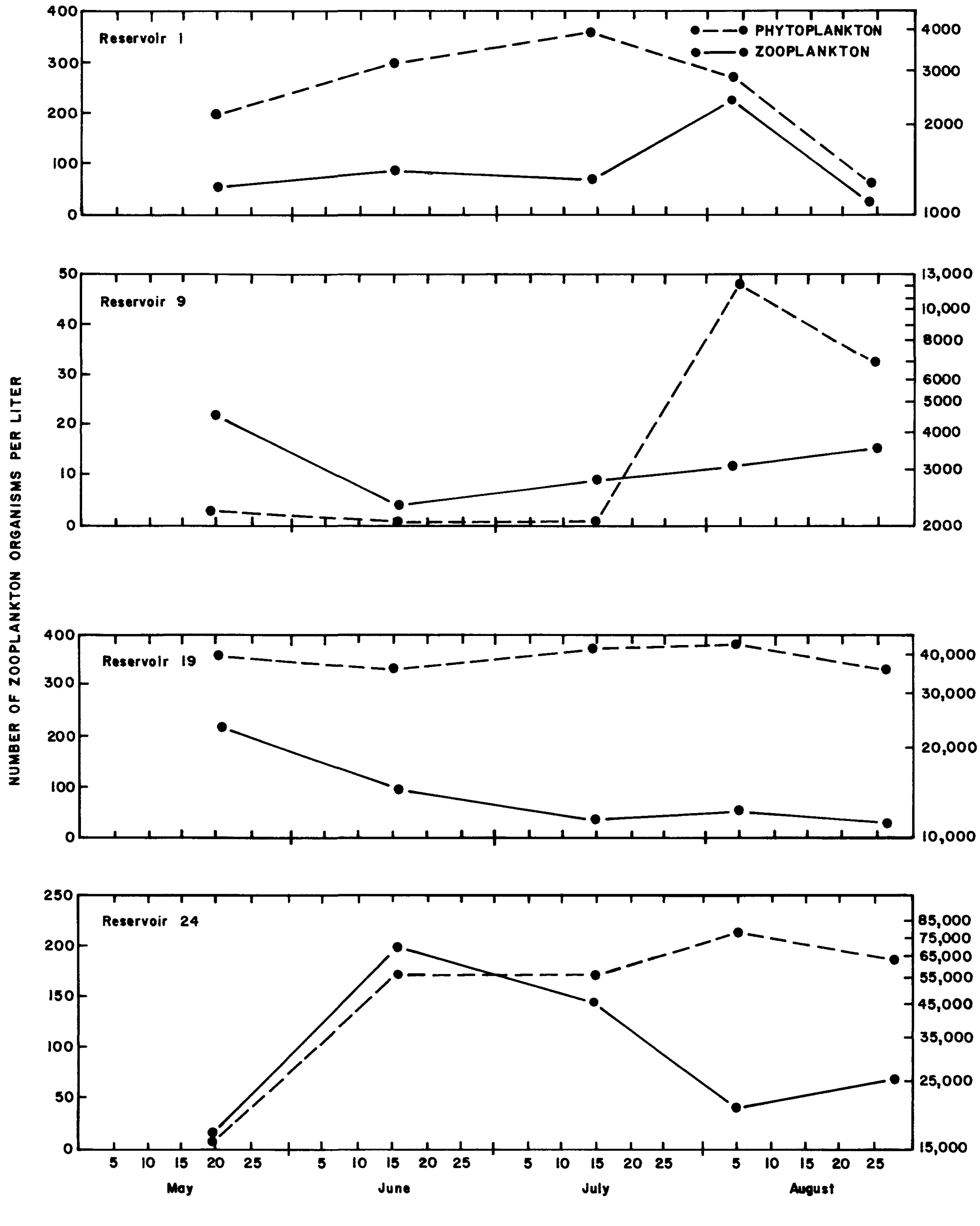


Figure 22.--Variation in the number of zooplankton organisms and phytoplankton cells at a depth of 1 meter in reservoirs 1, 9, 19, and 24 on five sampling dates (May through August).

sampling dates in this study, reservoirs 9, 19, and 24 had peak phytoplankton concentrations in early August (fig. 22). In reservoir 1 the peak cell concentration occurred in July.

Because phytoplankton cell concentrations are generally variable during spring and summer, lines connecting consecutive sampling points in figure 22 may not be representative of actual phytoplankton cell concentrations. However, among all the reservoirs, a common pattern for phytoplankton concentrations was a slight increase between the June and July sampling and a decrease from the early to late August sampling. The overall increase in phytoplankton concentration coincides with the seasonal increase in water temperatures. Increasing day length also probably contributes to increased phytoplankton growth until summer solstice. The decrease in day length after summer solstice probably contributes, in part, to the decrease in phytoplankton cell concentrations. Although there was no consistent trend in nutrient concentrations between the two August samplings, other factors causing a decrease in phytoplankton concentrations might include complexing reactions that render nutrients unavailable for uptake or zooplankton grazing.

Detected differences in phytoplankton concentrations among the study reservoirs coincide with the relative differences detected in dissolved oxygen and pH. Reservoir 9, which had the smallest dissolved oxygen and pH differences between the near-surface and near-bottom water and the largest dissolved-oxygen concentrations and pH values in near-bottom water, had relatively small phytoplankton concentrations. Reservoir 19, which had the largest differences in pH and dissolved oxygen between the near-surface and near-bottom water and the smallest dissolved-oxygen concentrations and pH values in the near-bottom water, had relatively large phytoplankton concentrations. These relative differences demonstrate the effect that phytoplankton can have on water quality. Large concentrations of phytoplankton can greatly increase the dissolved-oxygen concentration and pH in the near-surface water, but with increased production there is an attending large accumulation of organic matter in the bottom sediment that can create a large oxygen demand.

Zooplankton

Zooplankton concentrations in samples collected from the reservoirs are presented in table 8 (Supplemental Information section at back of report). Six zooplankton taxa were detected, with the largest percentages occurring in the orders Cladocera and Copepoda of the phylum Arthropoda. These orders generally are the most abundant zooplanktors in lakes (Reid and Wood, 1976). The May and June samples in reservoir 1 and the June sample in reservoir 24 were the only samples containing organisms in the order Ploima of the phylum Rotifera. Except for the occurrence of *Daphnia ambigua* in the June sample, zooplankton in reservoir 9 consisted of a single species--*Cyclops bicuspidatus thomasi*. The reason for the occurrence of a single species in reservoir 9 is not known. However, *Cyclops bicuspidatus thomasi* was present in every reservoir during each sampling. The Copepoda *Diaptomus* sp. was collected only in reservoirs 19 and 24. The species of zooplankton that exist in each reservoir could persist year after year as indicated in other studies (Reid and Wood, 1976).

Changes in total number of zooplankton organisms per liter (fig. 22) varied among the reservoirs. Reservoir 9 generally contained the smallest number of zooplankton organisms. In reservoirs 1, 19, and 24 an inverse relationship between number of phytoplankton and number of zooplankton is indicated (fig. 22). This relationship is strong from June to early August in reservoir 1, weak during the same period in reservoir 19, and strong from June to late August in reservoir 24. From May to June in all the reservoirs, zooplankton and phytoplankton indicate a direct relationship; however, total numbers of both plankton are increasing in reservoirs 1 and 24 and decreasing in reservoirs 9 and 19. These data indicate that the presence of phytoplankton as food does not constitute the sole limiting factor for zooplankton. Several studies show this same lack of consistent correlation between zooplankton and phytoplankton (Reid and Wood, 1976). Generally, zooplankton population cycles in the summer are variable, probably affected by a combination of changing food supply; shifts in the quality of food; and predation by zooplankton, fish, and other organisms such as insects (Wetzel, 1975). In addition, the sampling in this study might not have been frequent enough to show the true relationship that exists between phytoplankton and zooplankton. The relative numbers of each group may be different depending on whether the samples were collected during an increasing or decreasing phase of population change.

Benthic invertebrates

The most numerous classes of benthic invertebrates collected from the study reservoirs in late August were Oligochaeta (aquatic worms) and Insecta (insects) (table 9; Supplemental Information section at back of report). Organisms from the class Crustacea, particularly *Hyallela azteca* (scuds), were numerous in the shore sample from reservoir 24. Mainly because of the large number of Oligochaeta and Crustacea, reservoir 24 was the most productive in terms of total number of organisms. However, reservoir 24 was also the only study reservoir from which Mollusca was not collected. The most numerous organisms in reservoirs 1, 9, and 19 were Diptera (flies), of which *Chironomus* sp. generally comprised the largest percentage.

Except for reservoir 9, a large percentage of the bottom sediments was void of plant life except for epipelic algae. These areas are inhabited in large numbers by Oligochaeta and *Chironomus* sp., because of the abundant food supply (sediment containing organic matter of internal and external origins and colonized with bacteria and other microorganisms) and freedom from other competing benthic organisms. In contrast to most other benthic invertebrates, both of these organisms can tolerate small dissolved-oxygen concentrations and anaerobic conditions for short periods of time.

Hyallela azteca is a common freshwater species and an omnivorous substrate feeder that consumes bacteria, algae, and particulate detritus. *Hyallela azteca* reaches maximum production rates at temperatures between 20° and 25°C, which was similar to the range of temperatures in the reservoirs during sampling. It is more numerous along the shores because of the large quantities of available food and larger dissolved-oxygen concentrations of near-surface water compared to concentrations in the deeper locations of the reservoirs. *Hyallela azteca* can be a main source of food for fish populations.

Reservoirs 1, 19, and 24 had similar total numbers of benthic invertebrate taxa collected from all three sampling locations. Reservoir 9 had almost twice as many benthic invertebrate taxa as the other reservoirs. Because of the greater number of taxa, even though total numbers of organisms were fewer, reservoir 9 had a larger diversity index (table 2) and therefore a more stable community than reservoirs 1, 19, and 24. Part of this diversity is the result of a more diverse environment provided by the extensive growths of macrophytes along the reservoir bottom. Disregarding other factors, stable benthic invertebrate communities are more able to sustain fish populations than unstable communities.

Table 2.--*Diversity index of benthic invertebrates collected from each reservoir during August 1981*

[Calculations based on combined numbers of individuals and taxa from all three sampling locations in each reservoir]

Reservoir	Diversity index	
	Brillouin[1]	Shannon-Weaver[2]
1	1.13	1.65
9	2.13	3.09
19	1.30	1.89
24	1.22	1.77

[1]Diversity index (from Brillouin, 1962): $H = \frac{1}{N} \log \frac{N!}{N_1!N_2!\ldots N_s!}$

[2]Diversity index (from Wilhm and Dorris, 1968): $H = -\sum_{i=1}^{s} \frac{N_i}{N} \log \frac{N_i}{N}$

where in both equations H is Diversity Index (information per individual),
N is the total number of individuals,
s is the total number of taxa, and
N_i $(i=1,2,\ldots s)$ is the number of individuals in the ith species.

Fecal bacteria

Reservoirs 19 and 24 generally had larger fecal coliform and fecal streptococcal bacteria concentrations than reservoirs 1 and 9 (table 10; Supplemental Information section at back of report). There were no consistent trends in bacterial concentrations among the study reservoirs, nor were there consistent differences between shore and midpoint bacterial concentrations. The ratio between the fecal coliform and fecal streptococcal concentrations generally was less than 1.0 in reservoirs 1 and 9 and greater than 1.0 in reservoirs 19 and 24. However, interpretation of the data is difficult because of nonideal colony counts. Most of the bacteria presumably originated from livestock and waterfowl waste, which can be a variable nonpoint source of contamination. Although cattle were observed only at reservoir 9, cattle waste was present in drainages of the other reservoirs. Studies indicate that 100-day-old cattle wastes can release fecal coliform in concentrations that exceed recreational water-quality criteria (Kress and Gifford, 1984). In addition, waterfowl were observed at least once in each of the reservoirs.

DIEL TRENDS

Onsite measurements

At measurement depth of 1 meter

Water temperature, measured dissolved-oxygen concentrations, and calculated dissolved-oxygen concentrations at saturation are plotted in figure 23. Values of pH and specific conductance are plotted in figure 24.

Temperature

Water temperatures measured at a depth of 1 m followed trends in ambient air temperatures, with diel fluctuations having a lag time of several hours. The diel trends of water temperature are similar among the four reservoirs, with maximum temperatures occurring during mid- to late afternoon (1500-1800 hours) and minimum temperatures occurring during mid-morning (0900-1000 hours). Temperature fluctuation throughout the day was small, averaging 2.1 C° for the four reservoirs. The maximum temperature measured at a depth of 1 m was 22.9°C in reservoir 1.

Late August was chosen for the diel sampling under the assumption that limnological conditions would be most stressful for aquatic biota. Proposed reservoir uses other than fish production, in general, would not be expected to be affected by diel changes in water quality. Reservoir temperatures at a depth of 1 m did not exceed 23°C, which is less than the maximum range of 23.9°-33.9°C recommended for successful spawning and growth of fish species such as largemouth bass, catfish, buffalo, bluegill, and perch (National Technical Advisory Committee to the Secretary of the Interior, 1968). However, temperatures greater than 20°C for prolonged periods can be lethal to species such as trout and northern pike.

Dissolved oxygen

Calculated dissolved oxygen at saturation showed little change throughout the day in each reservoir, in contrast to measured concentrations of dissolved oxygen, which showed pronounced fluctuations during 24 hours. Maximum dissolved-oxygen concentrations measured in the reservoirs generally occurred late in the evening (1800-2000 hours) just prior to sunset. A gradual decrease in dissolved oxygen continued through the night and generally reached a minimum in reservoirs 9, 19, and 24 from 0700 to 0800 hours. Problems with the continuous recorder at reservoir 1 limited dissolved-oxygen data to measurements about every 3 hours with the multi-parameter instrument. The lowest dissolved-oxygen measurement at this site was obtained at 0200 hours.

Although dissolved-oxygen trends at a depth of 1 m were similar among the reservoirs, concentrations varied considerably. Reservoirs 1 and 9 had oxygen maxima at concentrations considerably greater than saturation. Measured dissolved-oxygen concentrations at a depth of 1 m ranged from 5.0 to 9.5 mg/L in reservoir 1 and from 6.0 to 10.2 mg/L in reservoir 9. Of all the reservoirs, reservoir 9 had the largest diel oxygen maximum and the most symmetrical pattern relative to saturation. Reservoir 19 was unique among the four reservoirs in that measured values of dissolved oxygen were always less than saturation, ranging from 3.2 to 6.8 mg/L. Reservoir 24 had the smallest diel dissolved-oxygen minimum; however, its

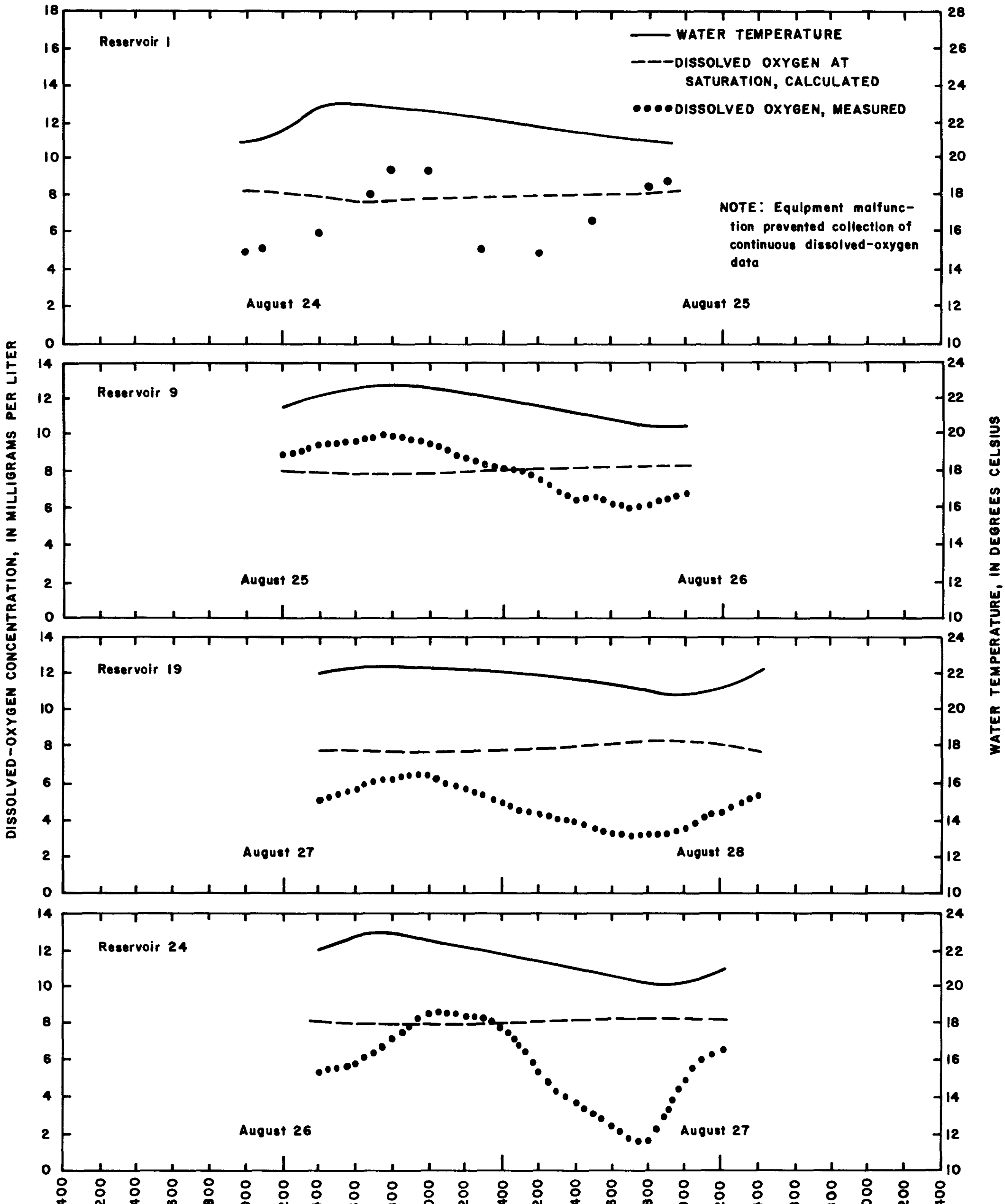


Figure 23.--Variation of water temperature and dissolved-oxygen concentration at a depth of 1 meter in reservoirs 1, 9, 19, and 24 during 24 hours in late August.

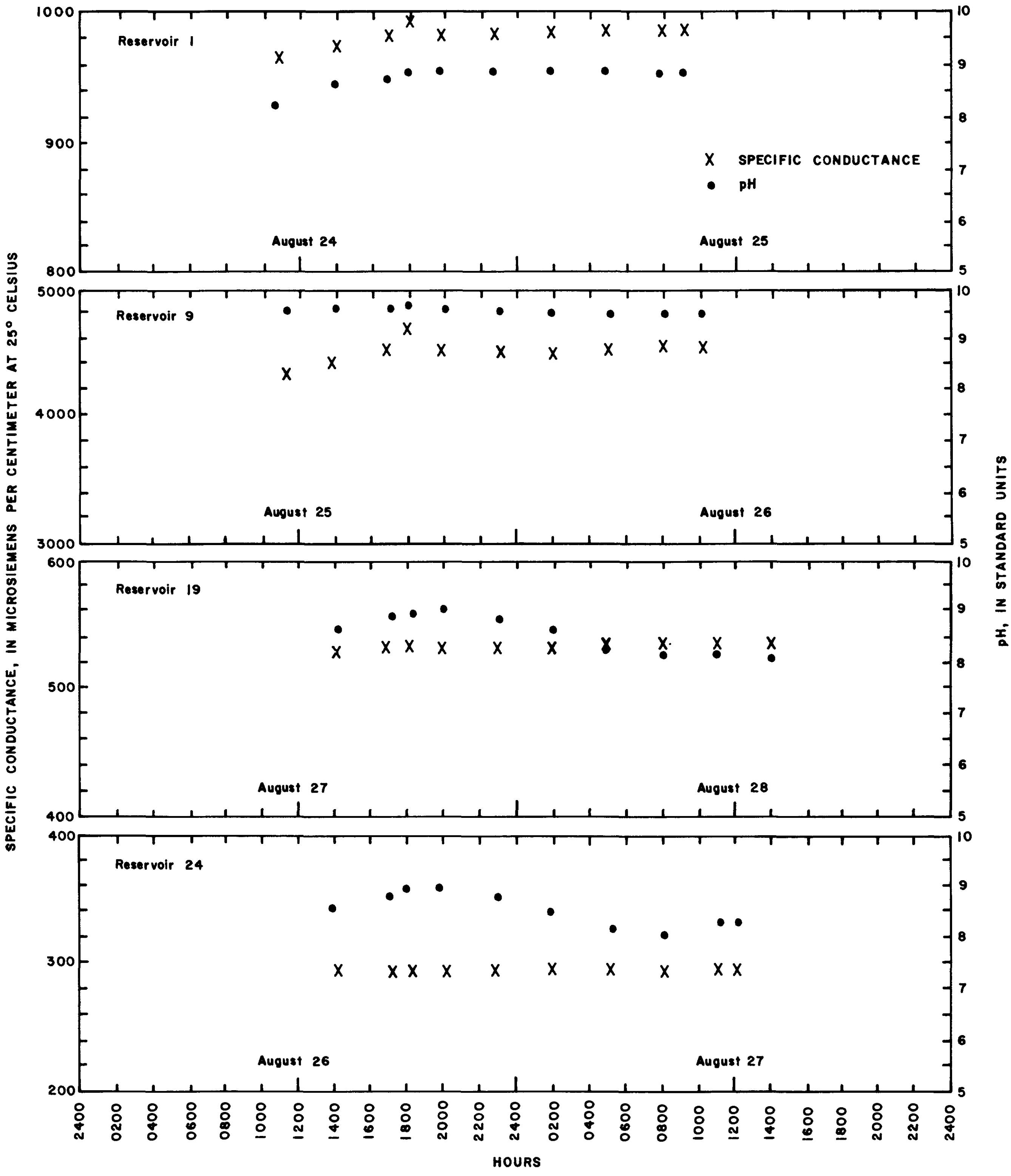


Figure 24.--Variation of pH and specific conductance at a depth of 1 meter in reservoirs 1, 9, 19, and 24 during 24 hours in late August.

dissolved-oxygen maximum exceeded saturation, producing the largest diel fluctuation (1.8-8.9 mg/L).

Diel patterns at the 1.0-m depth result from dissolved oxygen produced by photosynthesis during daylight hours surpassing the oxygen demand of respiration and decomposition, and accumulating to a maximum between 1800 and 2000 hours. As sunlight decreases, the rate of photosynthetic oxygen production decreases and finally stops, beginning a trend toward oxygen depletion. Cellular respiration and bacterial decomposition of organic matter consume oxygen, creating an oxygen minimum between 0700 and 0800 hours in each reservoir except reservoir 1. In reservoir 1, oxygen concentrations began to increase at 0200 hours, presumably in response to strong winds that caused mixing of aerated surface water with water at the 1.0-m depth.

The undersaturation of oxygen maxima in reservoir 19 may have been due to greater rates of decomposition assumed to occur in the thick bottom muds of this reservoir. Reservoirs 1 and 9 had larger dissolved-oxygen concentrations during the daylight hours than reservoirs 19 and 24, possibly because of additional production by the dense growths of aquatic macrophytes along the shore and reservoir bottom. Reservoir 24, with the largest range of diel fluctuation, was very turbid and had a noticeable humic-brown (organic) coloration. The presence of a large phytoplankton population in reservoir 24, coupled with the presence of large quantities of organic matter in the bottom sediment, could explain the considerable variations in dissolved-oxygen concentrations.

Small dissolved-oxygen concentrations affect fish production more than the other proposed reservoir uses. Within existing ranges of the study reservoirs, dissolved-oxygen availability imposes greater restrictions on aquatic biota than temperature. In fact, a major problem with increased temperature in water is that it decreases the solubility of dissolved oxygen while concomitantly leading to increased rates of oxygen consumption through accelerated metabolic demands and bacterial decomposition. Although the increased rate of metabolism may result in a greater production of oxygen through photosynthesis during the day, it may also result in greater deficits at night, and prolonged oxygen deficits substantially less than saturation during the night can severely stress desirable forms of aquatic organisms. A minimum concentration of 5.0 mg/L has been recommended by the U.S. Environmental Protection Agency (1978) to protect freshwater aquatic life and to support a diverse fish population. Reservoirs 1 and 9 sustained oxygen levels equal to or greater than 5.0 mg/L throughout the 24 hours at the 1.0-m depth, which would indicate suitable conditions for fish propagation. Dissolved-oxygen concentrations in reservoir 19 decreased to less than 5.0 mg/L for an extended time. Reservoir 24, although maintaining oxygen concentrations in excess of 5.0 mg/L for much of the day, decreased to 1.8 mg/L during the early morning hours. Dissolved-oxygen concentrations measured at the 1.0-m depth in reservoirs 19 and 24 probably would be considered marginal for supporting viable populations of fish and other oxygen-sensitive aquatic organisms.

pH

Diel fluctuations of pH at the 1.0-m depth were less than 1.0 standard unit in all four reservoirs (fig. 24). Maximum pH values occurred in late afternoon and generally corresponded to the time of maximum dissolved-oxygen concentrations. Reservoirs 1 and 9 had the least change in pH throughout the day, with ranges of

8.2 to 8.8 in reservoir 1 and 9.4 to 9.7 in reservoir 9. The pH changed from 8.2 to 9.1 in reservoir 19 and from 8.0 to 8.9 in reservoir 24. Changes in pH are related to the uptake and release of CO_2 through primary production by phytoplankton and respiration and decomposition of all aquatic organisms.

Diel values of pH measured at the 1.0-m depth generally were within limits suitable for most freshwater aquatic life, waterfowl, and livestock, except during late afternoon. Although aquatic organisms can become acclimated to temporary exposure outside protective ranges, fishery production generally deteriorates as pH values diverge from the recommended range. In all the reservoirs, the maximum pH values in late afternoon either were near or exceeded the criteria protective of fish, waterfowl, and livestock. At the 1.0-m depth, reservoir 9 continuously exceeded and reservoir 19 temporarily exceeded the pH criterion of 9.0, whereas reservoirs 1 and 24 were very close to the limit. The pH in all reservoirs exceeded the criterion protective of recreational swimming.

Specific conductance

Diel fluctuations of specific conductance at the 1.0-m depth (fig. 24) in the reservoirs were minimal, with no evident trends. Reservoir 9 had the largest diel fluctuation and also the largest values, ranging from 4,300 to 4,620 µS/cm. The smallest values and smallest fluctuation, 290 to 294 µS/cm, occurred at reservoir 24. Specific-conductance values fluctuated from 965 to 991 µS/cm at reservoir 1 and from 530 to 542 µS/cm at reservoir 19. The relatively small variation in pH values at the 1.0-m depth limits diel changes in dissolution-precipitation reactions that might otherwise affect specific conductance.

Profiles

Depth-profile measurements of water temperature, dissolved oxygen, pH, and specific conductance were made at 1800 (presunset) and 0500 (predawn) hours. These measurements were made to assist in the detection of diel water-quality changes.

Temperature

Profiles of water temperature in each reservoir (figs. 25-28) indicate lower temperatures in the near-surface water at 0500 hours compared to 1800 hours. Near-surface water temperatures at 0500 hours ranged from 20.7°C in reservoir 24 to 21.9°C in reservoir 19. Near-surface water temperatures at 1800 hours ranged from 22.5°C in reservoir 19 to 24.0°C in reservoir 9. Generally, there was little difference in the temperature of near-bottom water of each reservoir between the two times.

Temperature gradations from near-surface to near-bottom water in each reservoir were not maintained between the two profile times. Temperature differences between the near-surface and near-bottom waters at 1800 hours ranged from 2.1C° at reservoir 24 to 2.8C° at reservoirs 1 and 9. In reservoirs 9 and 24 following night-long heat loss from the water surface, the near-surface water had cooled to about the temperature of the near-bottom water.

During periods of solar radiation, water temperatures in reservoirs 9 and 24 increased throughout the entire depth. In reservoirs 1 and 19, which are deeper

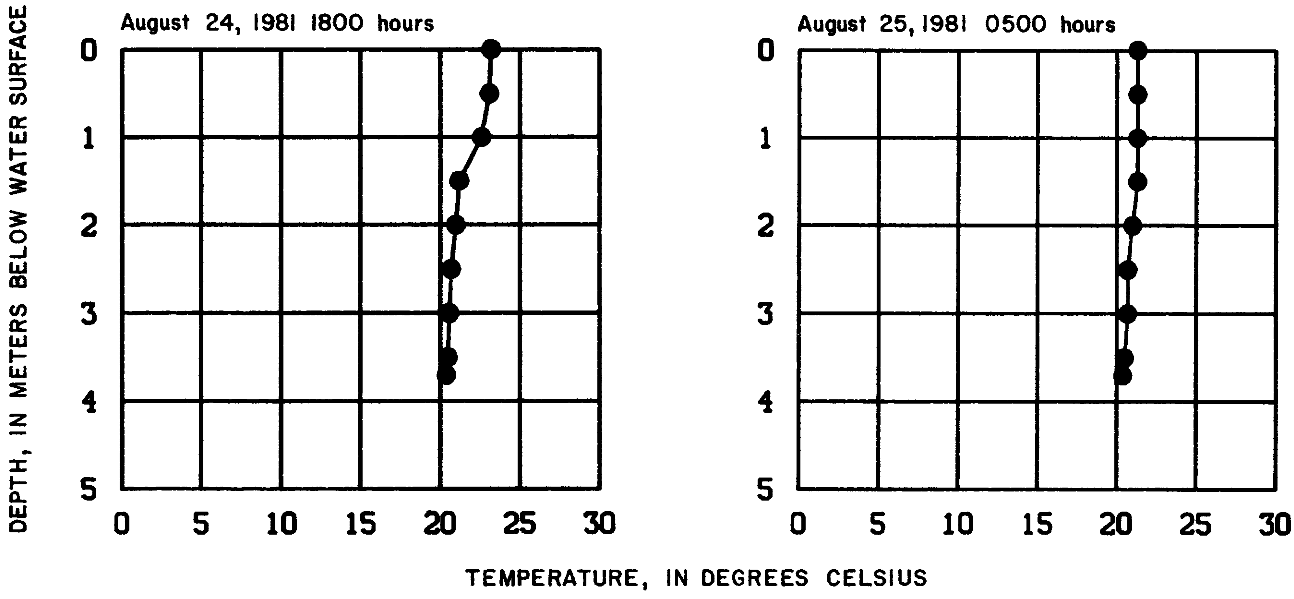


Figure 25.--Evening and morning depth profiles of temperature in late August in reservoir 1.

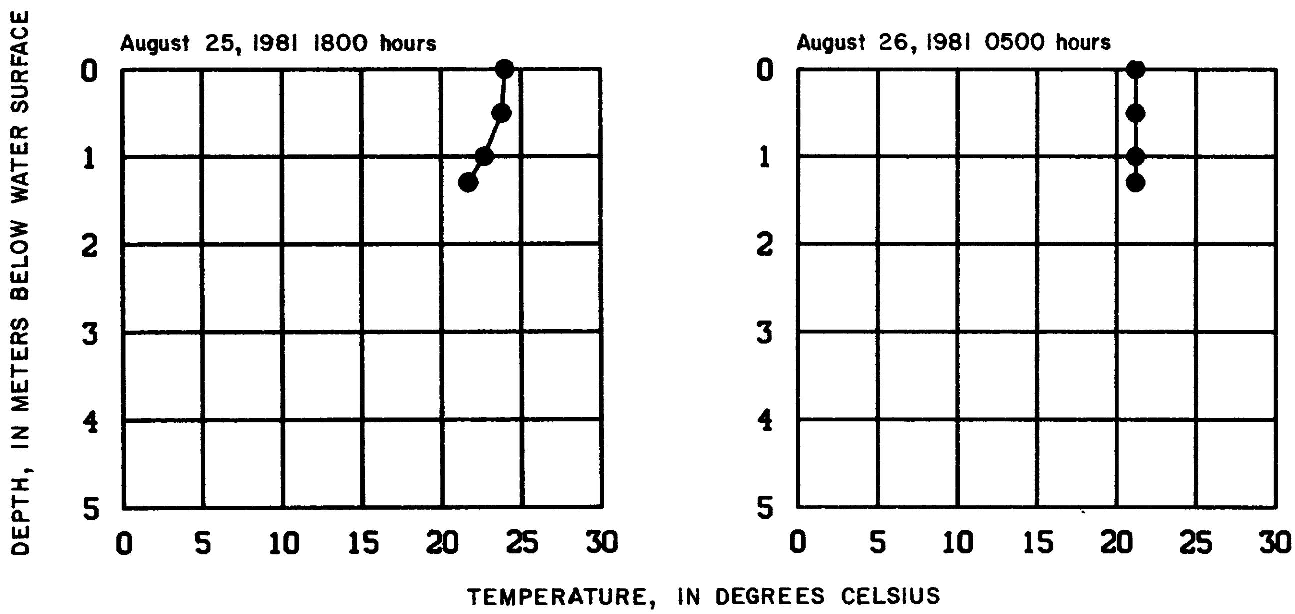


Figure 26.--Evening and morning depth profiles of temperature in late August in reservoir 9.

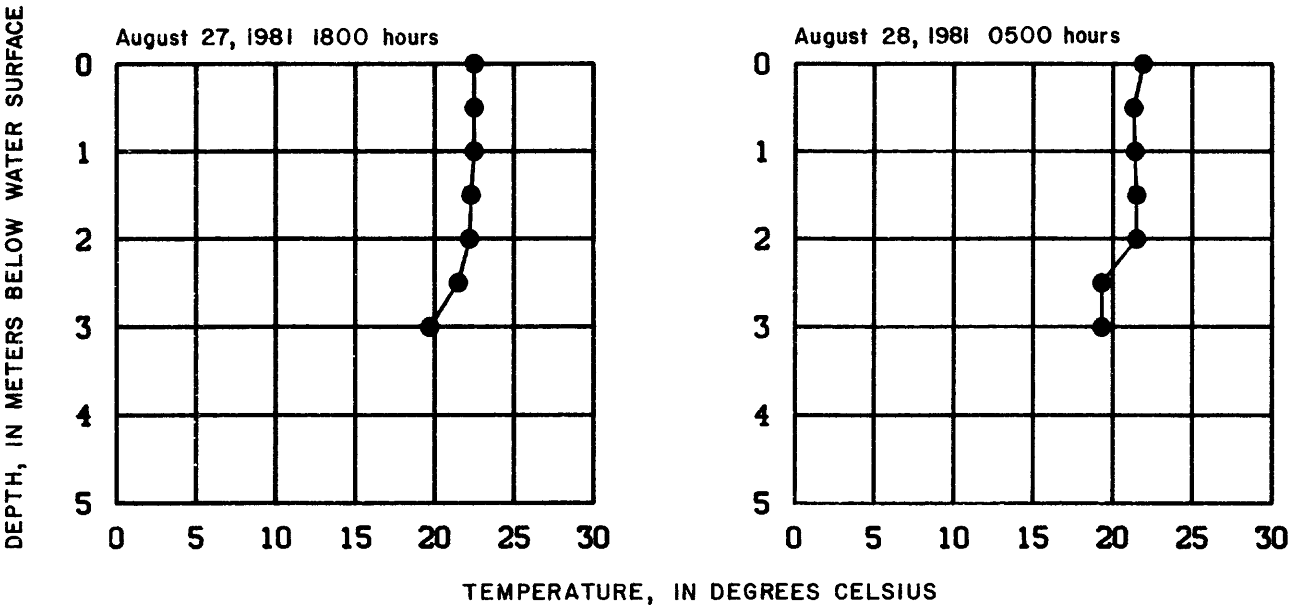


Figure 27.--Evening and morning depth profiles of temperature in late August in reservoir 19.

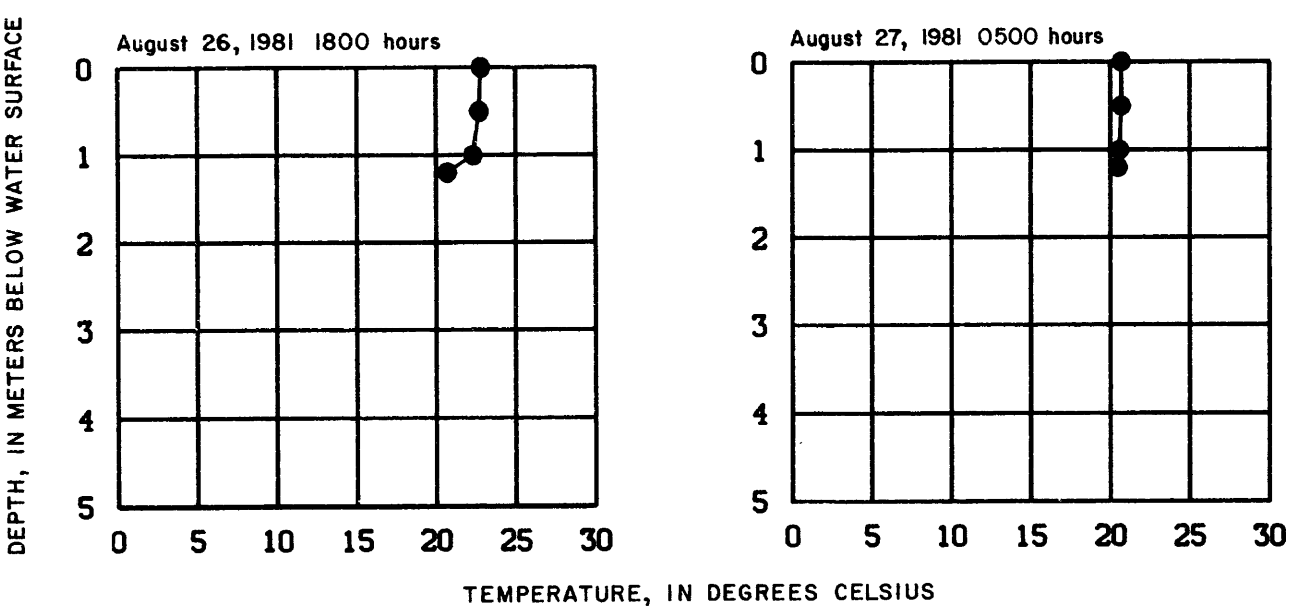


Figure 28.--Evening and morning depth profiles of temperature in late August in reservoir 24.

than reservoirs 9 and 24, warming and cooling also occurred but were restricted primarily to the upper 2.0 m. Because of the greater heat capacity per square unit of surface area in the deeper reservoirs, the available solar radiation was not enough to cause a temperature change in the near-bottom water of the deeper reservoirs. Consequently, reservoirs 1 and 19 maintained constant near-bottom temperatures between 0500 and 1800 hours.

Dissolved oxygen

Depth profiles of dissolved oxygen (figs. 29-32) illustrate larger concentrations of dissolved oxygen throughout the water column at 1800 hours than at 0500 hours. Except in reservoir 9, the oxygen maxima in the reservoirs occurred near the surface and the minima occurred near the bottom. In reservoir 9, the oxygen maximum measured at 1800 hours occurred near middepth at 1.0 m.

The largest differences between maximum and minimum dissolved-oxygen concentrations within the water column of each reservoir occurred at 1800 hours. Of the four reservoirs, reservoir 1 had the largest difference at 1800 hours, with dissolved-oxygen concentrations ranging from 11.2 mg/L near the surface to 2.7 mg/L near the bottom. The smallest difference at 1800 hours occurred in reservoir 9 with dissolved-oxygen concentrations ranging from 10.1 to 8.6 mg/L. Although differences between maximum and minimum dissolved-oxygen concentrations at 1800 hours were similar in reservoirs 19 and 24, concentrations in reservoir 19 (6.8-0.3 mg/L) were considerably smaller than in reservoir 24 (9.9-3.5 mg/L).

At 0500 hours, reservoir 1 again had the largest difference in dissolved-oxygen concentrations, with concentrations varying from 6.8 mg/L near the surface to 1.9 mg/L near the bottom. The smallest difference at 0500 hours was measured in reservoir 24 (2.7-2.3 mg/L). Reservoir 9 maintained the largest dissolved-oxygen concentrations (7.4-6.6 mg/L) throughout the water column at 0500 hours, whereas dissolved-oxygen concentrations in reservoir 19 decreased from 3.7 mg/L near the surface to the smallest measured oxygen minimum of 0.1 mg/L near the bottom.

Dissolved-oxygen concentrations with respect to saturation varied considerably between 1800 and 0500 hours. All reservoirs except reservoir 19 had oxygen concentrations in excess of saturation in the near surface at 1800 hours and all had less than saturation throughout their water columns at 0500 hours. In reservoir 19, oxygen concentrations never exceeded saturation near the surface and decreased to less than 4 percent of saturation near the bottom during both sampling hours. Reservoir 9 maintained supersaturated oxygen conditions through its entire depth at 1800 hours.

Differences determined between the 1800- and 0500-hour dissolved-oxygen profiles for each reservoir are caused by oxygen production during photosynthesis and oxygen utilization during respiration and decomposition of aquatic organisms. Because phytoplankton are more numerous in the upper part of the water column, dissolved-oxygen concentrations greater than saturation will occur there during the evening (1800 hours) following day-long oxygen production. Daytime and nighttime respiration and decomposition throughout the water column virtually occur at the same rate so that the net effect is a larger range of dissolved-oxygen concentrations at 1800 hours than at 0500 hours.

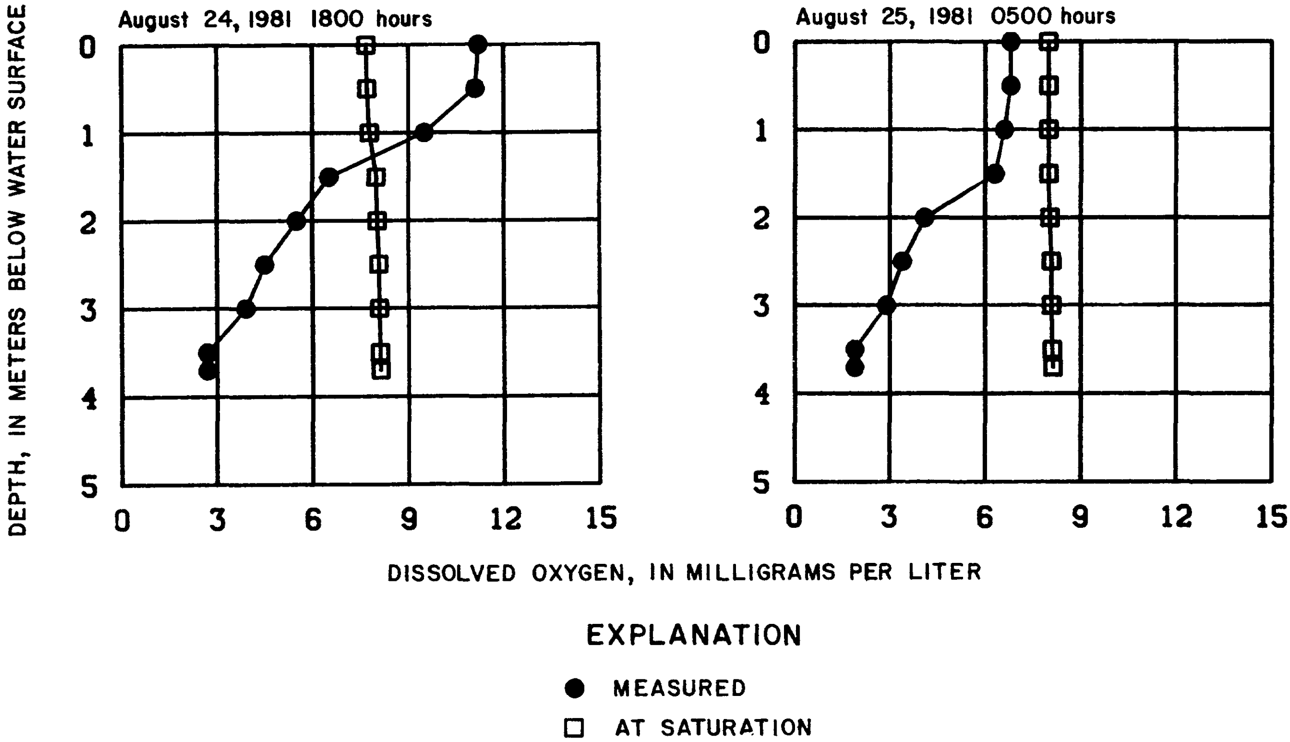


Figure 29.--Evening and morning depth profiles of dissolved oxygen in late August in reservoir 1.

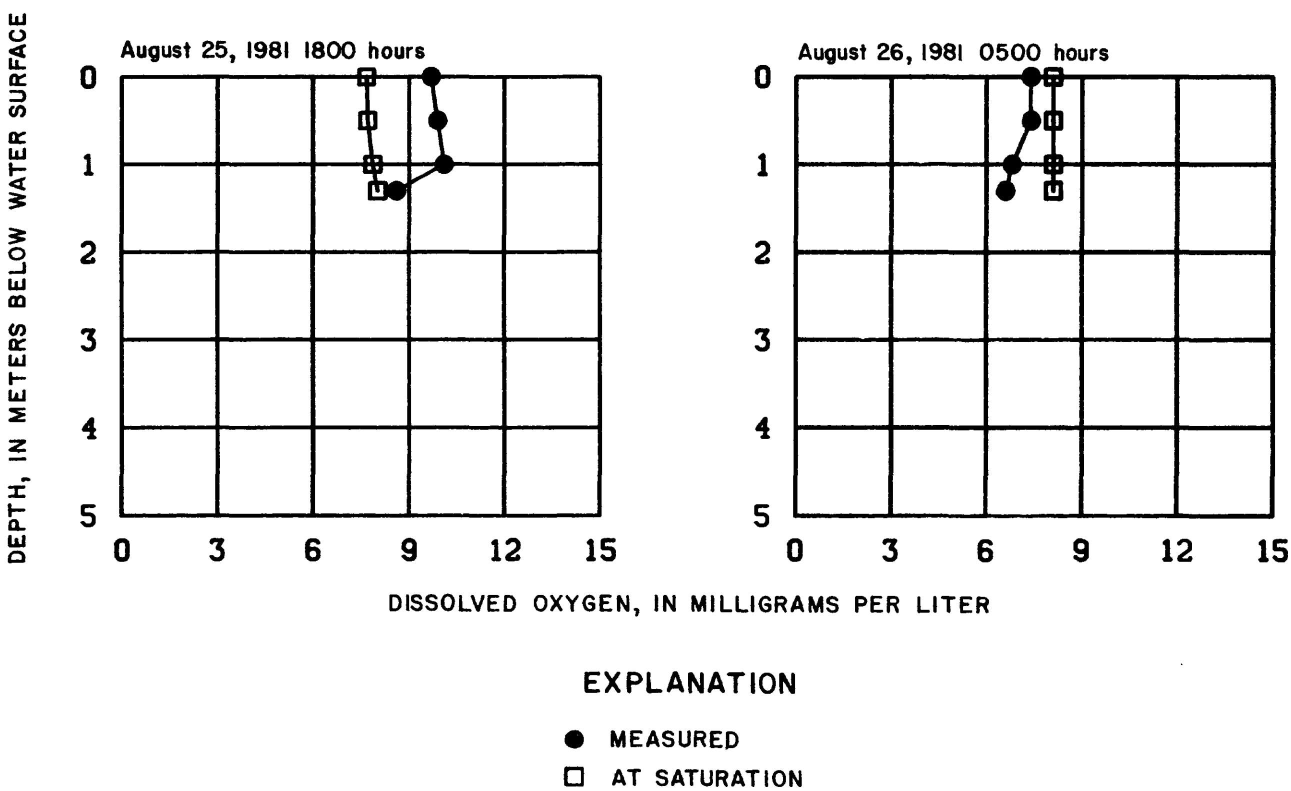
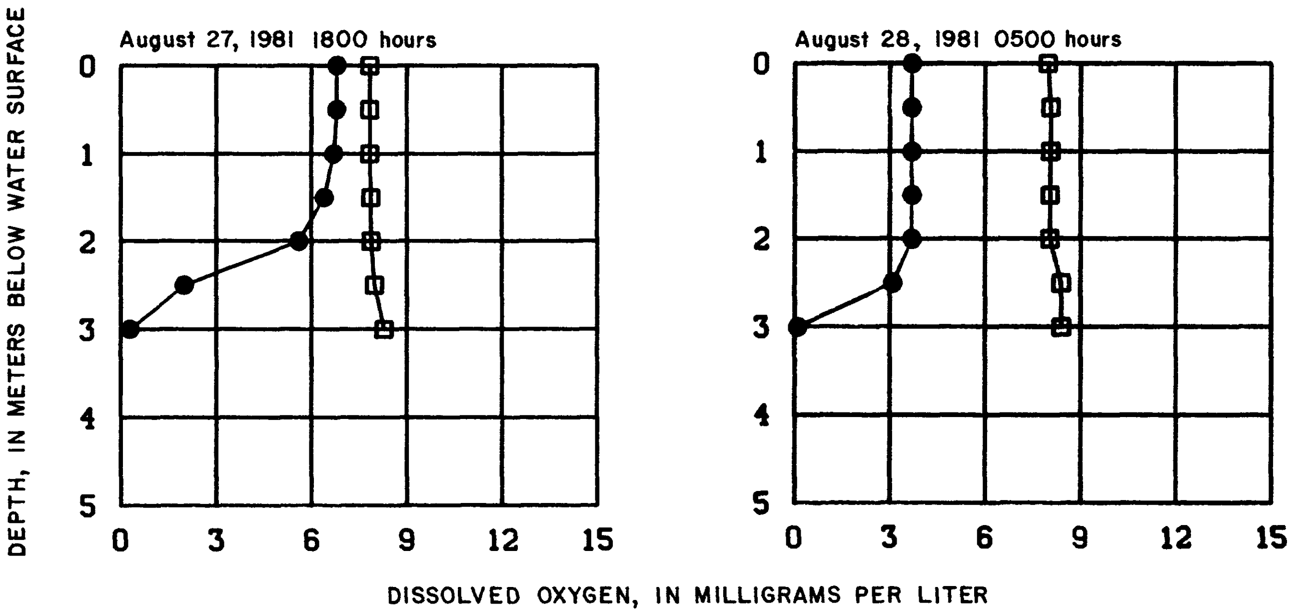


Figure 30.--Evening and morning depth profiles of dissolved oxygen in late August in reservoir 9.

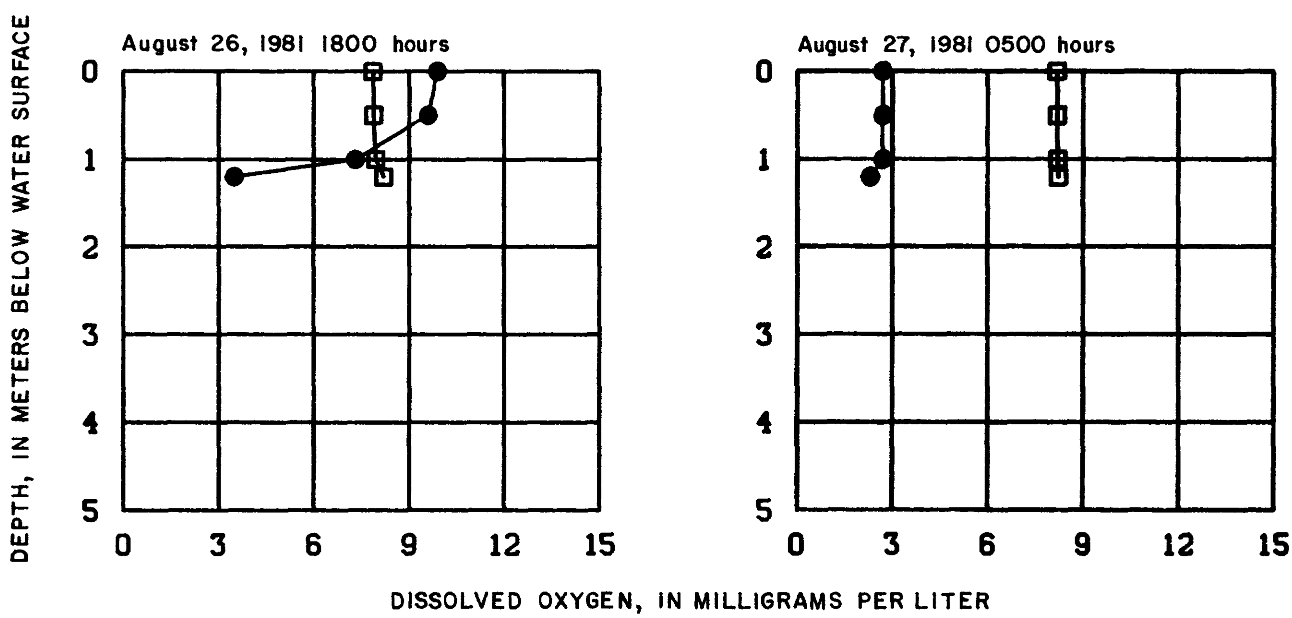


EXPLANATION

● MEASURED

□ AT SATURATION

Figure 31.--Evening and morning depth profiles of dissolved oxygen in late August in reservoir 19.



EXPLANATION

● MEASURED

□ AT SATURATION

Figure 32.--Evening and morning depth profiles of dissolved oxygen in late August in reservoir 24.

Differences in dissolved-oxygen profiles among the reservoirs basically result from differences in abundance and distribution of aquatic plants (algae and macrophytes). Submersed macrophytes growing from the bottom of reservoir 9 to middepth could be the cause of the oxygen maximum at middepth. In addition, macrophyte growth along the bottom of reservoir 9 would produce oxygen in the lower column of water and result in the small change in dissolved-oxygen concentration with depth.

Reservoir 1 had relatively small nutrient and phytoplankton concentrations compared to the other reservoirs. However, being the second-oldest reservoir would presumably account for greater accumulations of organic sediment compared to the younger reservoirs. The large difference in dissolved-oxygen concentrations with depth in reservoir 1, in part, is due to increased decomposition rates of this accumulated organic matter and increased production rates by phytoplankton and dense macrophytes along shore.

Large respiration and decomposition rates relative to oxygen production could account for undersaturated dissolved-oxygen concentrations in reservoir 19 at 1800 and 0500 hours and the small dissolved-oxygen concentrations in the near-surface water of reservoir 24 at 0500 hours. Large production rates compared to reservoirs 1 and 9 are indicated in reservoirs 19 and 24 by their large phytoplankton concentrations. However, with these increased production rates there can be attendant large populations of consumers in higher trophic levels and dieoffs of algal cells after blooms. With large numbers of organisms there is increased respiration and increased organic matter available for decomposition. In addition, cattle wastes could be another source of decomposable organic material. Such increased respiration and accumulation of organics would produce a large oxygen demand, which could keep the dissolved-oxygen concentration at less than saturation.

Under conditions such as the large dissolved-oxygen gradients in reservoir 1, mobile organisms such as fish can migrate to upper waters where dissolved-oxygen concentrations are more favorable. However, bottom-dwelling invertebrates are restricted to the deeper oxygen-deficient waters and may become stressed. Reservoir 9, which either exceeded or was near saturation throughout its depth, had oxygen concentrations suitable for many warm-water organisms. Reservoir 19, which did not reach dissolved-oxygen saturation near the surface during either profile, approached anaerobic conditions in the near-bottom water. It is unlikely that the limited oxygen availability of this reservoir during late summer could support viable populations of oxygen-sensitive organisms. Reservoir 24 maintained relatively large oxygen concentrations within the upper 1.0 m of water at 1800 hours. However, very small concentrations persisted throughout the entire depth at 0500 hours, which would severely stress or inhibit oxygen-sensitive organisms.

pH

Depth profiles of pH during diel sampling (figs. 33-36) showed little change with depth or time. Values of pH at 1800 hours were only slightly larger than those at 0500 hours. Variation in pH with depth was less than 1.0 standard unit in each reservoir for both sampling hours. Maximum values of pH occurred near the surface and minimum values occurred near the bottom. The maximum near-surface water pH was 9.8 at 1800 hours in reservoir 9 and the minimum near-bottom water pH was 7.8 at 0500 hours in reservoir 19.

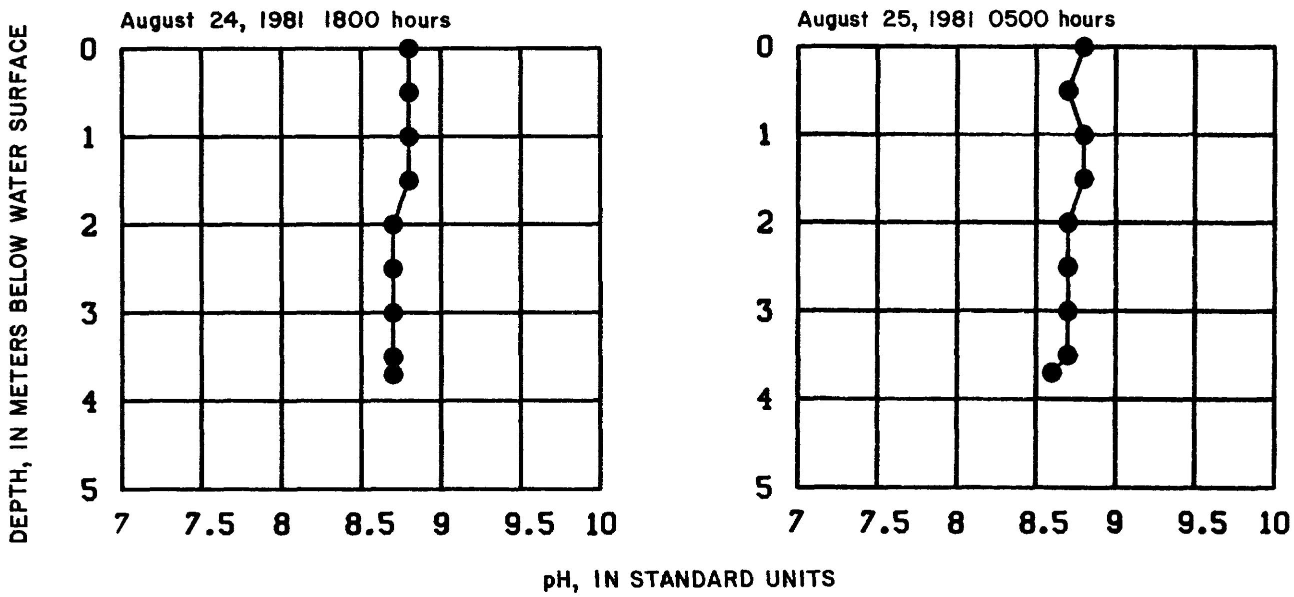


Figure 33.--Evening and morning depth profiles of pH in late August in reservoir 1.

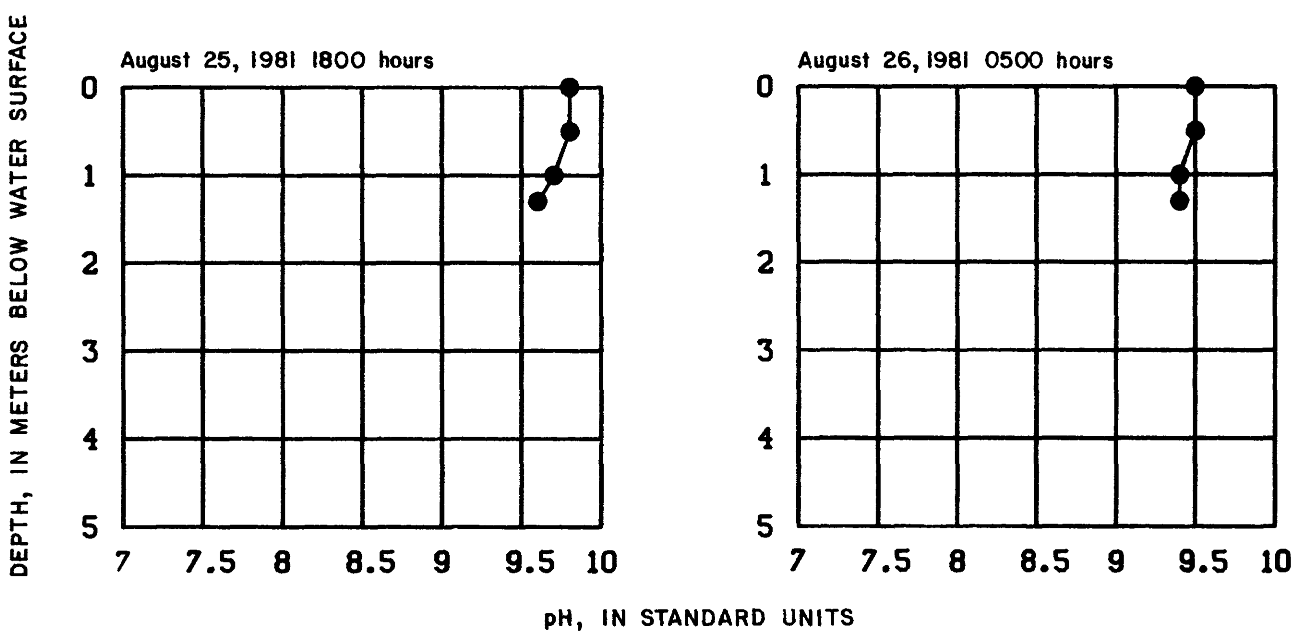


Figure 34.--Evening and morning depth profiles of pH in late August in reservoir 9.

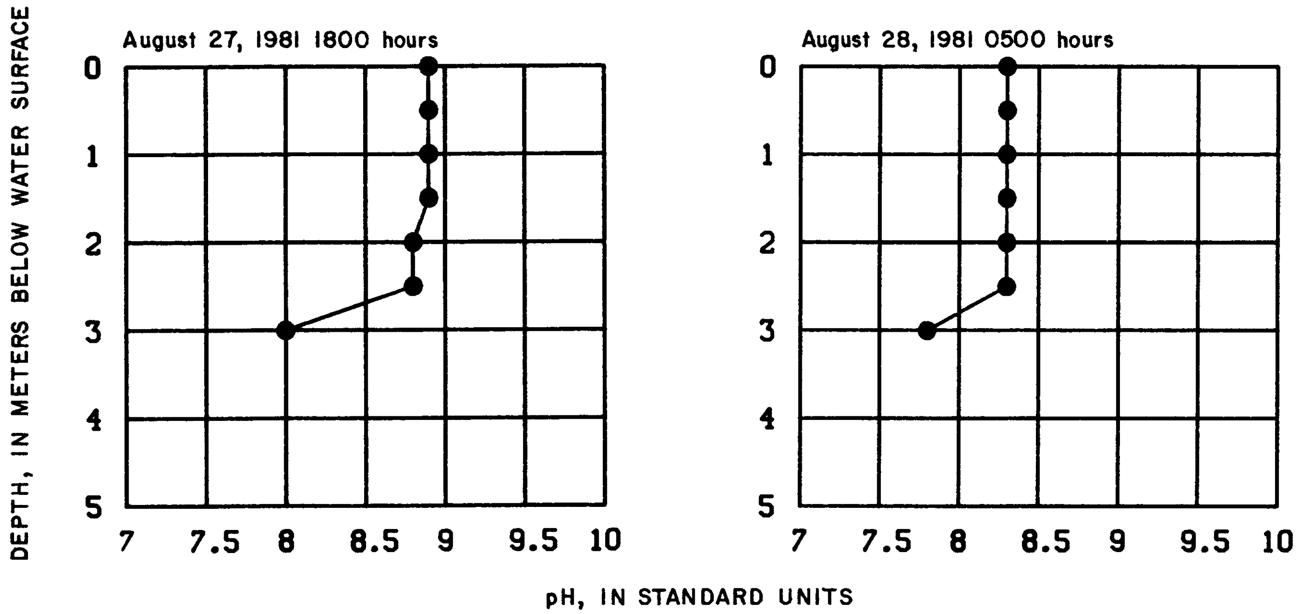


Figure 35.--Evening and morning depth profiles of pH in late August in reservoir 19.

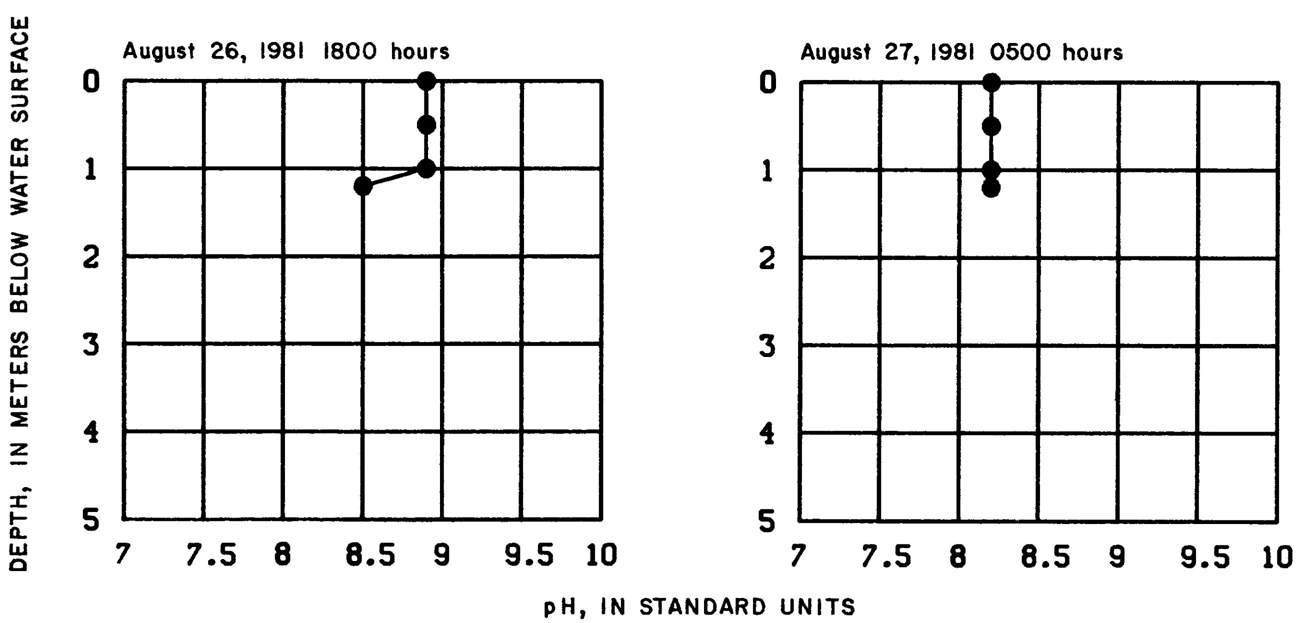


Figure 36.--Evening and morning depth profiles of pH in late August in reservoir 24.

Profiles of pH revealed no major diel fluctuations or variation with depth, indicating that the effect of photosynthesis and respiration on pH was sufficiently buffered. Values of pH remained relatively large throughout the entire depths of each reservoir and probably did not significantly increase the solubility of metal compounds in bottom sediments during the night.

Specific conductance

Specific-conductance profiles during diel sampling (figs. 37-40) showed little variation with depth or time. The difference in values from near-surface to near-bottom water was slightly larger at 1800 hours than at 0500 hours. The maximum range measured in the reservoirs was 40 μS/cm at 1800 hours in reservoir 9.

Chemical analyses

Major dissolved constituents

Generally, concentrations of major dissolved constituents (table 4) showed little change between the two sampling hours. In addition, only minor differences in concentrations were detected between samples collected at depths of 1.0 and 3.0 m in reservoirs 1 and 19.

The absence of any major differences between the 1800- and 0500-hour samples for major dissolved constituents, nutrients, and trace elements indicates negligible fluctuations in chemical composition on a diel basis. Major dissolved constituents would not be expected to vary significantly during 24 hours in shallow reservoirs where pH is relatively stable and wind can cause complete mixing.

Nutrients

Nutrient samples collected for analysis of nitrogen, phosphorus, and carbon concentrations (table 5) generally indicated only minor differences between the 1800- and 0500-hour sampling periods and between the depths of 1.0 and 3.0 m in reservoirs 1 and 19. Total organic carbon had the most consistent variation among the reservoirs, with increased concentrations at 0500 hours compared to 1800 hours in reservoirs 1, 19, and 24. In general, nutrient concentrations were slightly more variable than major dissolved constituents as a result of biological uptake and decay; however, differences were not consistent enough at all reservoirs to define trends.

Trace elements

Apparent diel variation in trace-element concentrations of lead and manganese occurred in the near-bottom samples of reservoirs 1 and 19 (table 6). In reservoir 1, increased total recoverable lead concentrations, from 5 μg/L (micrograms per liter) at 1800 hours to 39 μg/L at 0500 hours, may have been caused by bottom sediments entering the sample. Bottom-sediment contamination is probable because the dissolved-lead concentration did not increase. In reservoir 19, both dissolved and total recoverable manganese concentrations in the near-bottom samples were larger at 1800 hours than at 0500 hours. As noted by visual observation, the sediments in reservoir 19 were thick and dark, presumably containing large quantities of organic

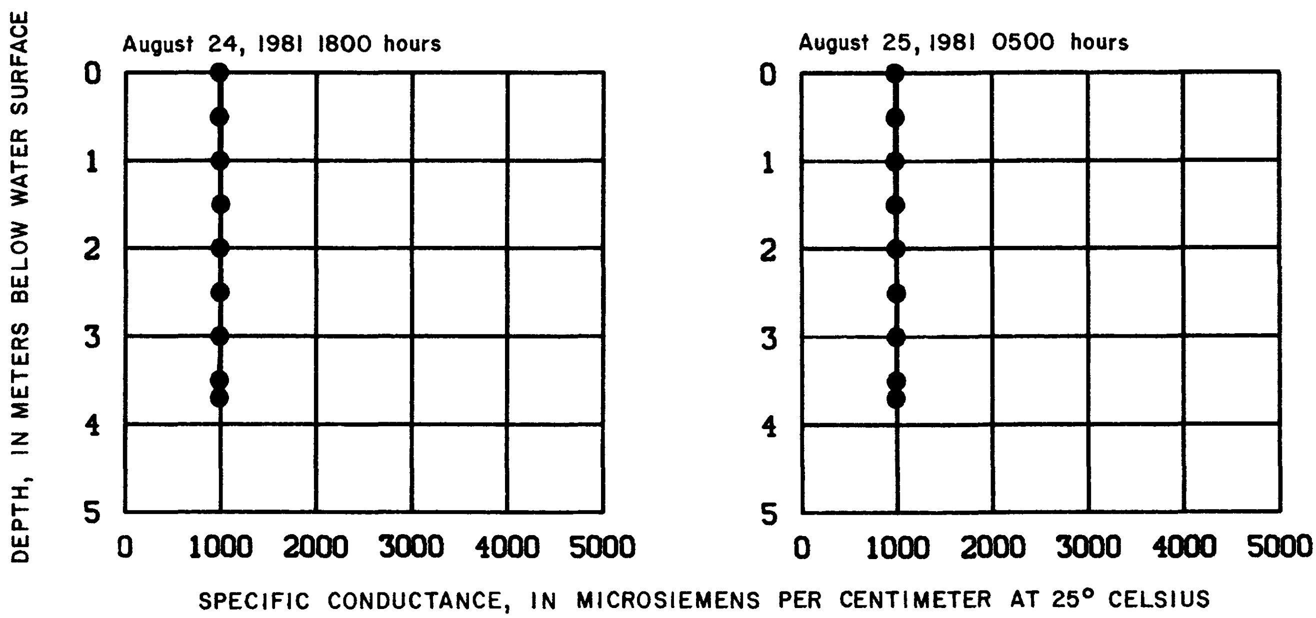


Figure 37.--Evening and morning depth profiles of specific conductance in late August in reservoir 1.

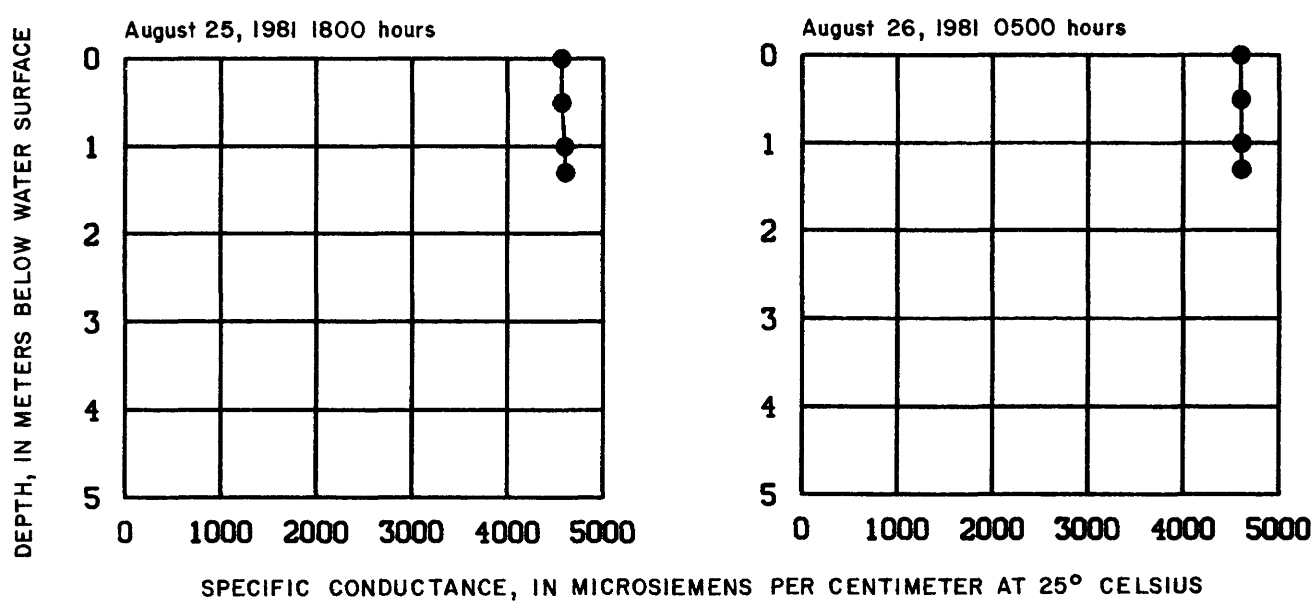


Figure 38.--Evening and morning depth profiles of specific conductance in late August in reservoir 9.

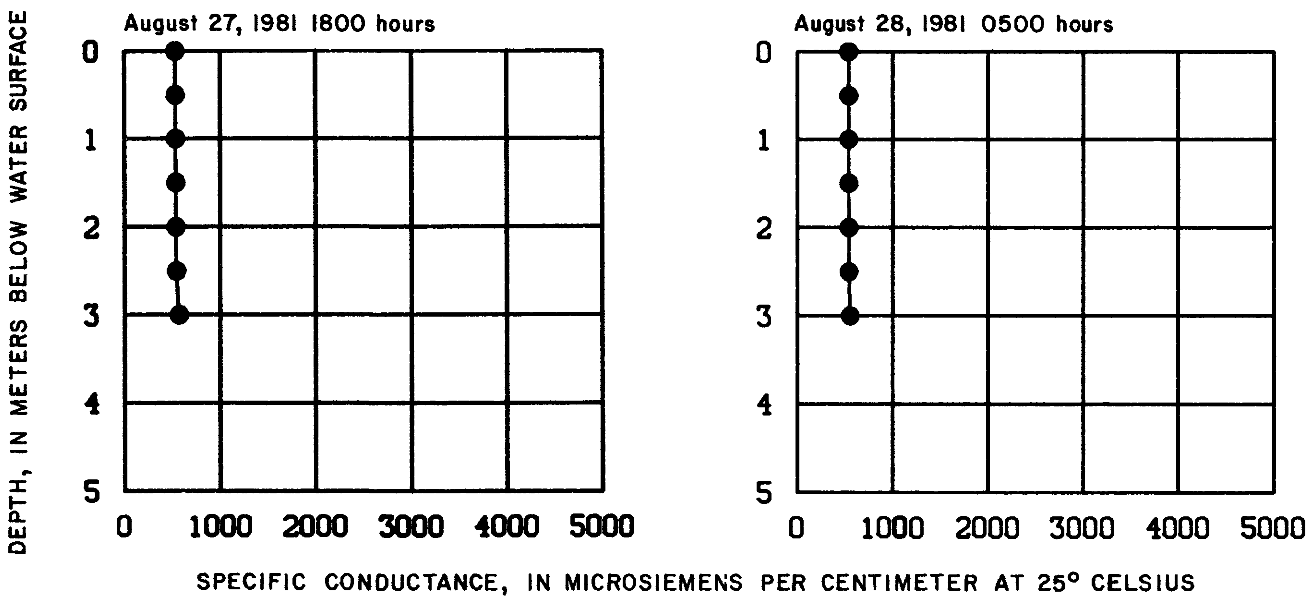


Figure 39.--Evening and morning depth profiles of specific conductance in late August in reservoir 19.

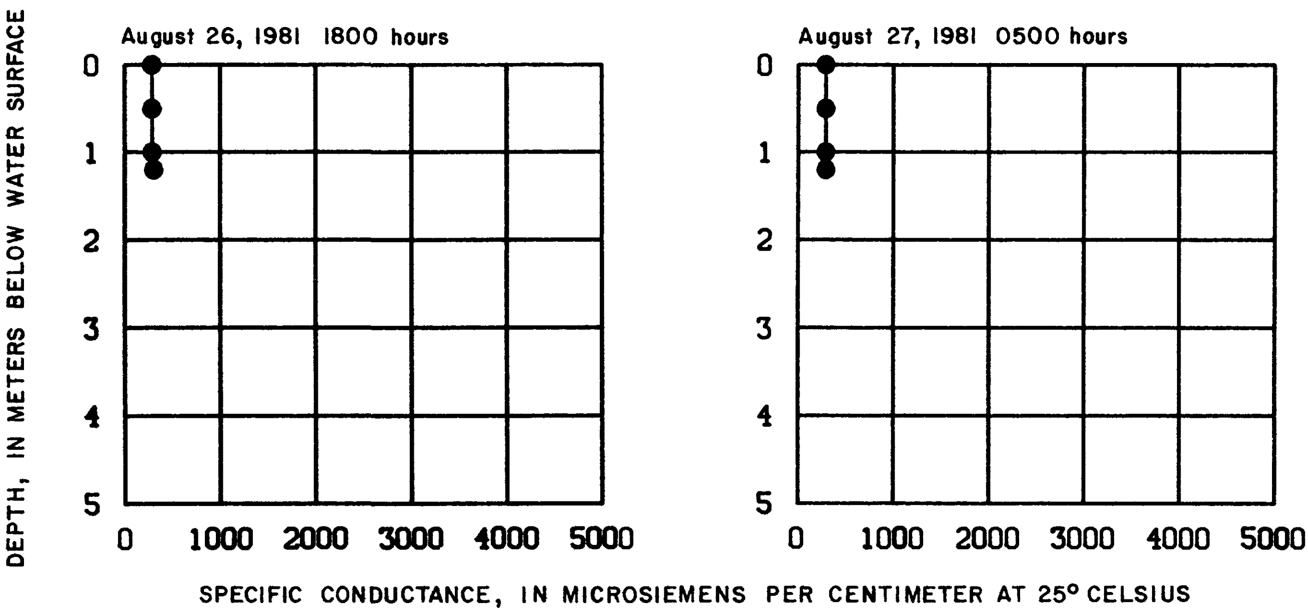


Figure 40.--Evening and morning depth profiles of specific conductance in late August in reservoir 24.

matter. Such organic matter commonly is enriched in manganese, which can be released through reduction and bacterial action as dissolved oxygen and pH decrease during the night (figs. 23 and 24) (Hem, 1970). Because larger manganese concentrations occurred at 1800 hours rather than at 0500 hours, sediment contamination in the samples from reservoir 19 also is probable.

Biological analyses

Concentrations of chlorophyll *a* and *b* (table 3) showed moderate and inconsistent fluctuations between the 1800- and 0500-hour sampling periods and between the 1.0- and 3.0-m sampling depths in reservoirs 1 and 19. Only one analysis was available for reservoir 9, which precludes comparison between sampling times. Chlorophyll *a* and *b* concentrations were significantly larger in reservoirs 19 and 24 than in reservoirs 1 and 9. Chlorophyll *b* concentrations, although much smaller than chlorophyll *a*, generally followed the same patterns in each reservoir.

Table 3.--*Concentrations of chlorophyll a and b collected during the diel sampling*

Reservoir	Date	Time (24-hour)	Sampling depth (meters)	Concentration, in micrograms per liter	
				Chlorophyll *a*	Chlorophyll *b*
1	08-24-81	1802	1.0	15.5	1.41
1	08-24-81	1806	3.0	1.87	.305
1	08-25-81	0502	1.0	6.08	.526
1	08-25-81	0506	3.0	2.26	.270
9	08-25-81	1802	1.0	6.62	.217
19	08-27-81	1802	1.0	42.1	10.7
19	08-27-81	1806	3.0	80.5	16.0
19	08-28-81	0502	1.0	75.9	15.4
19	08-28-81	0506	3.0	52.8	11.9
24	08-26-81	1802	1.0	272	46.4
24	08-27-81	0502	1.0	150	27.4

Because phytoplankton are passive and move with water currents, their distribution in a shallow reservoir can be extremely variable. However, many viable phytoplankton cells would be expected to occur in the upper water where sunlight conditions are more favorable for photosynthesis. This upper water occurrence may account for the generally larger chlorophyll concentrations measured in the near-surface samples of reservoirs 1 and 19. The differences in chlorophyll concentrations between 1800 and 0500 hours are variable and may occur because of uneven mixing due to temperature changes.

Chlorophyll *a* concentration can be considered as one manifestation of nutrient enrichment in the process of eutrophication. Taylor and others (1980) list a criterion of greater than 10.0 μg/L for chlorophyll *a* as indicative of eutrophic conditions in lakes not dominated by macrophytes. With the exception of reservoir

9, which contained abundant macrophytes, the study reservoirs all contained at least one sample exceeding 10.0 μg/L. Chlorophyll *a* concentration in reservoirs 19 and 24 greatly exceeded 10 μg/L in all samples, whereas reservoir 1 had concentrations much less than 10 μg/L in all samples except 1. Therefore, chlorophyll *a* concentrations indicate that reservoirs 19 and 24 are probably in more advanced stages of eutrophication than reservoir 1.

CONCLUSIONS

Water quality of the study reservoirs is affected by regional and local mineralogy, physical characteristics, and land use. Reservoirs 19 and 24 have drainages underlain entirely by the Bearpaw Shale and therefore are affected by the same regional mineralogy. These two reservoirs have larger manganese concentrations, smaller dissolved-solids concentrations, greater turbidity, and larger nitrogen (total nitrogen and total ammonia) concentrations than reservoirs 1 and 9. The larger nutrient concentrations of reservoirs 19 and 24 result in larger phytoplankton and chlorophyll *a* and *b* concentrations compared to reservoirs 1 and 9. However, the reservoirs do not show the same paired comparisons when grouped by water type, presumably as a result of differences in local mineralogy. Reservoir 19 has sodium bicarbonate sulfate water and reservoir 24, like reservoir 1, has sodium bicarbonate water. Reservoir 9 has sodium sulfate water.

Differences in water quality caused by mineralogy and land use mask differences caused by reservoir age. Virtually closed reservoirs, such as the study reservoirs, generally would attain large concentrations of water-quality constituents through years of continued water loss by evapotranspiration. However in the study area, dissolved-solids, phosphorus, and total organic carbon concentrations in the younger reservoirs (reservoirs 9 and 24) are both smaller and larger than in the older reservoirs (reservoirs 1 and 19). Consequently, no clear relationship between age and stage of eutrophication can be shown.

Trends from May to August that are similar among all the reservoirs include relatively uniform water temperature increases at all depths, increased differences between near-surface and near-bottom water dissolved-oxygen concentrations and pH, and an increase in concentration of dissolved solids. The uniform increase in water temperature at all depths is possible because the shallowness of the reservoirs allows frequent mixing. The progressive increase in the difference between near-surface and near-bottom water for dissolved-oxygen concentrations and pH results primarily from differing ratios of photosynthesis, respiration, and decomposition. The seasonal increase in the concentration of dissolved solids most likely is due to cumulative water losses by evapotranspiration.

The study reservoirs are considered to be enriched with nutrients. Consequently, they have the potential to support large concentrations of phytoplankton. Generally, with large concentrations of phytoplankton, daytime dissolved-oxygen concentrations and pH values are large. Among all the reservoirs, inconsistent monthly fluctuations in composition and concentration of phytoplankton result in variable dissolved-oxygen concentrations and pH values. However, reservoir 1, which had one of the smaller phytoplankton and chlorophyll *a* and *b* concentrations, had one of the larger dissolved-oxygen concentrations and pH values; conversely, reservoir 24, which had the largest phytoplankton and chlorophyll *a* and *b* concentrations did not have the largest dissolved-oxygen concentrations and pH values. This dichotomy demonstrates that phytoplankton production is not the sole biological factor affecting dissolved oxygen and pH, but works in conjunction with other factors--principally respiration by all aquatic organisms and decomposition.

Although all reservoirs contained similar types of planktonic organisms, they were present in different proportions. Phytoplankton-cell concentrations were largest in reservoir 24 and smallest in reservoirs 1 and 9. However, reservoirs 1 and 9 supported large growths of macrophytes. Monthly changes in zooplankton concentrations varied among the reservoirs. There was no consistent correlation between the concentration of zooplankton and the concentration of phytoplankton--their food source.

Benthic invertebrates in bottom sediments of each reservoir were composed of large numbers of Oligochaeta and *Chironomus* sp. These organisms feed on large food supplies of bacteria and other micro-organisms colonized on the sediment. *Hyallela azteca* was common along the shore, particularly in reservoir 24. Bacteria, algae, and particulate detritus provide abundant food for these organisms. Although the total number of organisms were fewer in reservoir 9 than in reservoirs 1, 19, and 24, reservoir 9 had a stable, diverse benthic community.

There were no consistent monthly trends in fecal bacteria concentration among the study reservoirs, nor were there consistent differences between shore and midpoint bacterial concentrations. Most of the fecal bacteria existing in the reservoirs presumably originated from livestock and waterfowl waste, which can be a variable nonpoint source of contamination.

The reservoirs are subject to frequent mixing by moderate winds because of their shallow depths and diminutive thermal stratification. Mixing prevents a sustained decrease of dissolved-oxygen concentrations in the near-bottom water. However, mixing also recirculates nutrients from the bottom sediments, enhancing growth of phytoplankton and production of organic matter for decomposition.

Major water-quality changes in the study reservoirs that could affect reservoir use were: an increase in selected trace-element concentrations from May to August, a decrease in dissolved-oxygen concentration during the night, and an increase in pH during the day. Fish propagation is more affected by these changes than are the other proposed reservoir uses of waterfowl habitat, livestock watering, and recreational swimming. Because of the concentrating effect of water loss through evaporation, August concentrations of total recoverable lead in reservoirs 19 and 24 exceeded by the greatest concentration the criterion protective of fish. Owing to large oxygen consumption by respiration and decomposition, nighttime dissolved-oxygen concentrations in reservoirs 19 and 24 were less than the criterion protective of fish. In contrast, large photosynthetic rates during the day resulted in all reservoirs approaching or exceeding the maximum limit of pH protective of all proposed reservoir uses in the late afternoon.

Because similar small reservoirs in eastern Montana evaluated during an earlier study have large nutrient concentrations, they also have the potential to support large phytoplankton concentrations, which could result in small dissolved-oxygen concentrations at night. Diel sampling in other reservoirs considered for fish propagation would delineate reservoirs in which water quality during the day is protective of fish but during the night attains stressful dissolved-oxygen concentrations.

REFERENCES CITED

Barica, Jan, 1974, Extreme fluctuations in water quality of eutrophic fish kill lakes--Effect of sediment mixing: Water Research, v. 8, no. 11, p. 881-888.

Brillouin, Leon, 1962, Science and information theory (2d ed.): New York, Academic Press, 347 p.

Cordell, G. V., Jr., 1971, Climate of Montana, *in* Climates of the States: National Oceanic and Atmospheric Administration, Climatography of the United States No. 60-24, 21 p.

Eisenlohr, W. S., Jr., and others, 1972, Hydrologic investigations of prairie potholes in North Dakota, 1959-68: U.S. Geological Survey Professional Paper 585-A, 102 p.

Ferreira, R. F., 1980, Limnological data for 12 reservoirs in Valley County, Montana: U.S. Geological Survey Open-File Report 80-339, 68 p.

______1983, Significance of water quality to fish propagation, waterfowl habitat, livestock watering, and recreation use for 24 reservoirs in Phillips and Valley Counties, Montana: U.S. Geological Survey Water-Resources Investigations Report 83-4008, 58 p.

Friedman, L. C., ed., 1979, Water-quality laboratory services catalog: U.S. Geological Survey Open-File Report 78-842, 499 p.

Greeson, P. E., Ehlke, T. A., Irwin, G. A., Lium, B. W., and Slack, K. V., 1977, Methods for collection and analysis of aquatic biological and microbiological samples: U.S. Geological Survey Techniques of Water-Resources Investigations, Book 5, Chapter A4, 332 p.

Hem, J. D., 1970, Study and interpretation of the chemical characteristics of natural water (2d ed.): U.S. Geological Survey Water-Supply Paper 1473, 363 p.

Hutchinson, G. E., 1967, A treatise on limnology--Volume 2, Introduction to lake biology and the limnoplankton: New York, John Wiley, 1115 p.

Kress, Michael, and Gifford, G. F., 1984, Fecal coliform release from cattle fecal deposits: Water Resources Bulletin, v. 20, no. 1, p. 61-66.

National Technical Advisory Committee to the Secretary of the Interior, 1968, Water quality criteria: Washington, D.C., U.S. Government Printing Office, 234 p.

Reid, G. K., and Wood, R. D., 1976, Ecology of inland waters and estuaries: New York, D. Van Norstrand, 485 p.

Ross, C. P., Andrews, D. A., and Witkind, I. J., compilers, 1955, Geologic map of Montana: U.S. Geological Survey, scale 1:500,000, 2 sheets.

Skougstad, M. N., Fishman, M. J., Friedman, L. C., Erdmann, D. E., and Duncan, S. S., eds., 1979, Methods for collection and analysis of water samples for dissolved minerals and gases: U.S. Geological Survey Techniques of Water-Resources Investigations, Book 5, Chapter A1, 625 p.

Taylor, W. D., Lambou, V. W., Williams, L. R., and Hern, S. C., 1980, Trophic state of lakes and reservoirs: U.S. Environmental Protection Agency Technical Report E-80-3, 15 p.

U.S. Department of Commerce, 1965, Climatic summary of the United States, Supplement for 1951 through 1960, Montana: U.S. Weather Bureau, Climatography of the United States No. 86-20, 111 p.

U.S. Environmental Protection Agency, 1978, Quality criteria for water, July 1976: Washington, D.C., U.S. Government Printing Office, 256 p.

______ 1980, Water quality criteria documents--Availability: Federal Register, v. 45, no. 231, November 28, Part V, p. 79318-79379.

Wetzel, R. J., 1975, Limnology: Philadelphia, W. B. Saunders, 743 p.

Wilhm, J. L., and Dorris, T. C., 1968, Biological parameters for water quality criteria: BioScience, v. 18, p. 477-481.

Zison, S. W., Haven, K. F., and Mills, W. B., 1977, Water quality assessment, a screening method for nondesignated 208 areas: U.S. Environmental Protection Agency EPA 600/9-77-023, 549 p.

SUPPLEMENTAL INFORMATION

Table 4.--*Major dissolved chemical constituents*

[Analyses by U.S. Geological Survey. Abbreviations: m, meter; mg/L, milligram per liter]

Date	Time (24-hour)	Sampling depth (m)	Hardness (mg/L as $CaCO_3$)	Hardness, noncarbonate (mg/L as $CaCO_3$)	Calcium, dissolved (mg/L as Ca)	Magnesium, dissolved (mg/L as Mg)	Sodium, dissolved (mg/L as Na)	Percent sodium	Sodium adsorption ratio
				RESERVOIR 1--AIR BASE POND					
May, 1981									
20 ...	0832	1.0	230	0.00	33	35	140	57	4.0
20 ...	0836	3.0	230	.00	33	35	140	57	4.0
June									
15 ...	1503	1.0	220	.00	27	36	140	58	4.2
15 ...	1507	3.0	220	.00	27	37	130	56	3.8
July									
14 ...	1547	1.0	200	.00	22	35	150	61	4.6
14 ...	1551	3.0	200	.00	21	35	150	62	4.7
Aug									
04 ...	1603	1.0	200	.00	20	36	150	61	5.5
04 ...	1607	3.0	200	.00	21	36	150	61	5.5
24 ...	1802	1.0	200	.00	21	36	150	61	5.5
24 ...	1806	3.0	210	.00	22	37	160	62	5.7
25 ...	0502	1.0	210	.00	21	38	160	62	5.7
25 ...	0506	3.0	200	.00	21	37	160	62	5.8

Date	Sampling depth (m)	Potassium, dissolved (mg/L as K)	Alkalinity, laboratory (mg/L as $CaCO_3$)	Sulfate, dissolved (mg/L as SO_4)	Chloride, dissolved (mg/L as Cl)	Fluoride, dissolved (mg/L as F)	Silica, dissolved (mg/L as SiO_2)	Solids, sum of constituents, dissolved (mg/L)
May, 1981								
20 ...	1.0	5.6	330	160	12	0.3	2.0	586
20 ...	3.0	5.8	330	170	12	.3	2.0	597
June								
15 ...	1.0	5.5	310	180	19	.3	2.7	597
15 ...	3.0	5.2	300	180	19	.3	2.8	582
July								
14 ...	1.0	5.3	300	180	21	.3	2.1	596
14 ...	3.0	5.3	300	190	21	.3	2.3	605
Aug								
04 ...	1.0	5.9	360	160	6.3	.5	2.3	597
04 ...	3.0	5.5	360	160	7.1	.5	2.9	600
24 ...	1.0	6.2	350	140	20	.4	2.9	587
24 ...	3.0	6.0	350	150	20	.4	3.3	609
25 ...	1.0	6.5	310	--	20	.4	3.0	--
25 ...	3.0	6.5	350	160	23	.4	3.6	623

Date	Time (24-hour)	Sampling depth (m)	Hardness (mg/L as $CaCO_3$)	Hardness, noncarbonate (mg/L as $CaCO_3$)	Calcium, dissolved (mg/L as Ca)	Magnesium, dissolved (mg/L as Mg)	Sodium, dissolved (mg/L as Na)	Percent sodium	Sodium adsorption ratio
				RESERVOIR 9--GAY RESERVOIR					
May, 1981									
20 ...	1403	1.0	1,000	920	200	130	500	51	6.8
June									
16 ...	0903	1.0	950	870	200	110	510	53	7.2
July									
15 ...	0903	1.0	980	940	180	130	620	57	8.6
Aug									
05 ...	0932	1.0	1,100	1,000	210	140	640	55	8.4
25 ...	1802	1.0	1,300	1,200	240	160	700	54	8.6
26 ...	0502	1.0	1,300	1,300	250	160	710	54	8.6

Date	Sampling depth (m)	Potassium, dissolved (mg/L as K)	Alkalinity, laboratory (mg/L as $CaCO_3$)	Sulfate, dissolved (mg/L as SO_4)	Chloride, dissolved (mg/L as Cl)	Fluoride, dissolved (mg/L as F)	Silica, dissolved (mg/L as SiO_2)	Solids, sum of constituents, dissolved (mg/L)
May, 1981								
20 ...	1.0	17	110	2,000	28	0.7	0.8	2,940
June								
16 ...	1.0	20	82	2,000	12	.7	.8	2,900
July								
15 ...	1.0	20	46	2,200	12	.8	.5	3,190
Aug								
05 ...	1.0	18	60	2,400	9.0	.7	3.4	3,460
25 ...	1.0	23	49	2,600	13	1.0	.1	3,770
26 ...	1.0	23	32	2,600	28	1.0	.7	3,790

Table 4.--*Major dissolved chemical constituents*--Continued

Date	Time (24-hour)	Sampling depth (m)	Hardness (mg/L as $CaCO_3$)	Hardness, noncarbonate (mg/L as $CaCO_3$)	Calcium, dissolved (mg/L as Ca)	Magnesium, dissolved (mg/L as Mg)	Sodium, dissolved (mg/L as Na)	Percent sodium	Sodium adsorption ratio
				RESERVOIR 19--KING RESERVOIR					
May, 1981									
21 ...	0732	1.0	140	18	34	13	55	44	2.0
21 ...	0736	3.0	95	.00	35	18	54	52	2.4
June									
16 ...	1803	1.0	140	21	35	13	61	47	2.2
16 ...	1807	3.0	150	28	36	14	57	44	2.0
July									
15 ...	1432	1.0	150	25	35	14	65	47	2.3
15 ...	1436	3.0	150	25	35	14	63	47	2.3
Aug									
05 ...	1802	1.0	120	3.0	28	13	61	49	2.6
05 ...	1806	3.0	110	.00	26	11	53	49	2.4
27 ...	1802	1.0	110	1.0	23	13	66	54	3.0
27 ...	1806	3.0	110	.00	23	12	63	54	2.9
28 ...	0502	1.0	110	10	23	12	65	54	3.0
28 ...	0506	3.0	110	.00	24	12	66	54	3.0

Date	Sampling depth (m)	Potassium, dissolved (mg/L as K)	Alkalinity, laboratory (mg/L as $CaCO_3$)	Sulfate, dissolved (mg/L as SO_4)	Chloride, dissolved (mg/L as Cl)	Fluoride, dissolved (mg/L as F)	Silica, dissolved (mg/L as SiO_2)	Solids, sum of constituents, dissolved (mg/L)
May, 1981								
21 ...	1.0	9.2	120	130	2.8	0.2	6.7	323
21 ...	3.0	9.1	120	110	2.4	.2	6.8	292
June								
16 ...	1.0	8.6	120	140	2.9	.2	8.0	341
16 ...	3.0	9.1	120	140	3.0	.2	8.2	340
July								
15 ...	1.0	9.8	120	170	3.1	.2	11	380
15 ...	3.0	9.9	120	160	3.2	.2	12	370
Aug								
05 ...	1.0	9.9	120	130	2.7	.5	12	329
05 ...	3.0	8.6	120	140	3.0	.5	11	326
27 ...	1.0	10	110	120	3.0	.2	14	315
27 ...	3.0	9.7	130	130	2.8	.2	14	333
28 ...	1.0	10	97	150	3.2	.2	14	336
28 ...	3.0	10	110	150	3.2	.0	14	346

Table 4.--*Major dissolved chemical constituents*--Continued

Date	Time (24-hour)	Sampling depth (m)	Hardness (mg/L as $CaCO_3$)	Hardness, noncarbonate (mg/L as $CaCO_3$)	Calcium, dissolved (mg/L as Ca)	Magnesium, dissolved (mg/L as Mg)	Sodium, dissolved (mg/L as Na)	Percent sodium	Sodium adsorption ratio
				RESERVOIR 24--EMPIRE RESERVOIR					
May, 1981									
20 ...	1932	1.0	46	0.00	13	3.2	21	47	1.4
June									
16 ...	1433	1.0	55	.00	15	4.3	25	47	1.5
July									
15 ...	1802	1.0	66	.00	18	5.1	26	43	1.4
Aug									
05 ...	1431	1.0	57	.00	15	4.8	29	49	1.8
26 ...	1802	1.0	56	.00	14	5.1	34	53	2.1
27 ...	0502	1.0	56	.00	14	5.1	35	54	2.2

Date	Sampling depth (m)	Potassium, dissolved (mg/L as K)	Alkalinity, laboratory (mg/L as $CaCO_3$)	Sulfate, dissolved (mg/L as SO_4)	Chloride, dissolved (mg/L as Cl)	Fluoride, dissolved (mg/L as F)	Silica, dissolved (mg/L as SiO_2)	Solids, sum of constituents, dissolved (mg/L)
May, 1981								
20 ...	1.0	5.0	62	37	2.5	0.1	3.1	123
June								
16 ...	1.0	5.6	83	23	2.6	.1	4.7	131
July								
15 ...	1.0	6.0	100	6.0	17	.1	9.8	148
Aug								
05 ...	1.0	6.6	120	2.0	3.3	.6	14	148
26 ...	1.0	7.0	140	1.0	3.8	.2	13	162
27 ...	1.0	7.2	130	2.0	2.9	.2	13	158

Table 5.--*Selected plant nutrients*

[Analyses by U.S. Geological Survey. Abbreviations and symbol: m, meter; mg/L, milligram per liter; <, less than]

Date	Time (24-hour)	Sampling depth (m)	Nitrogen, total (mg/L as N)	Nitrogen, NO_2+NO_3 dissolved (mg/L as N)	Nitrogen, NO_2+NO_3 total (mg/L as N)	Nitrogen, ammonia total (mg/L as N)	Nitrogen, organic total (mg/L as N)	Phosphorus, total (mg/L as P)	Phosphorus, ortho, dissolved (mg/L as P)	Carbon, organic, total (mg/L as C)
				RESERVOIR 1--AIR BASE POND						
May, 1981										
20 ...	0832	1.0	1.7	0.01	0.01	0.11	1.6	0.08	0.01	24
20 ...	0836	3.0	1.4	.01	.01	.11	1.3	.08	.01	17
June										
15 ...	1503	1.0	1.5	.01	.01	.07	1.4	.06	.04	21
15 ...	1507	3.0	1.6	.02	.02	.11	1.5	.08	.04	25
July										
14 ...	1547	1.0	1.8	.01	.02	.05	1.8	.11	.05	12
14 ...	1551	3.0	1.9	.02	.03	.13	1.8	.12	.05	13
Aug										
04 ...	1603	1.0	2.0	<.01	<.01	.17	1.8	.15	.09	15
04 ...	1607	3.0	1.9	<.01	<.01	.32	1.6	.23	.14	14
24 ...	1802	1.0	1.7	<.01	.01	.11	1.6	.23	.12	15
24 ...	1806	3.0	1.7	<.01	.01	.20	1.5	.23	.11	16
25 ...	0502	1.0	--	<.10	<.10	.12	1.8	.23	.02	23
25 ...	0506	3.0	--	<.10	<.10	.19	1.6	.25	.01	17
				RESERVOIR 9--GAY RESERVOIR						
May, 1981										
20 ...	1403	1.0	1.8	.01	.01	.12	1.7	.10	<.01	17
June										
16 ...	0903	1.0	1.4	.02	.01	.11	1.3	.06	.03	13
July										
15 ...	0903	1.0	1.4	.02	.04	.11	1.3	.05	.05	8
Aug										
05 ...	0932	1.0	2.4	<.01	<.01	.16	2.2	<.01	.01	23
25 ...	1802	1.0	--	.10	<.10	.10	1.5	.04	.01	14
26 ...	0502	1.0	1.4	<.10	<.10	.11	1.3	.06	<.01	14

Table 5.--*Selected plant nutrients*--Continued

Date	Time (24-hour)	Sampling depth (m)	Nitrogen, total (mg/L as N)	Nitrogen, NO_2+NO_3 dissolved (mg/L as N)	Nitrogen, NO_2+NO_3 total (mg/L as N)	Nitrogen, ammonia total (mg/L as N)	Nitrogen, organic total (mg/L as N)	Phosphorus, total (mg/L as P)	Phosphorus, ortho, dissolved (mg/L as P)	Carbon, organic, total (mg/L as C)
RESERVOIR 19--KING RESERVOIR										
May, 1981										
21 ...	0732	1.0	3.4	0.02	0.01	0.15	3.3	0.14	0.01	31
21 ...	0736	3.0	3.6	.02	.01	.20	3.4	.17	.01	31
June										
16 ...	1803	1.0	3.4	.02	<.01	.07	3.3	.17	.04	37
16 ...	1807	3.0	3.6	.02	<.01	.08	3.5	.17	.03	39
July										
15 ...	1432	1.0	4.0	.02	.03	.20	3.8	.16	.02	23
15 ...	1436	3.0	4.3	.02	.02	.42	3.9	.17	.01	22
Aug										
05 ...	1802	1.0	4.7	<.01	<.01	.23	4.5	.01	.01	22
05 ...	1806	3.0	4.3	<.01	<.01	.27	4.0	.01	.01	30
27 ...	1802	1.0	--	<.10	<.10	.15	3.8	.17	.02	24
27 ...	1806	3.0	5.1	<.10	.12	.47	4.5	.24	.04	22
28 ...	0502	1.0	--	.11	<.10	.19	3.1	.17	.01	25
28 ...	0506	3.0	--	.12	<.10	.43	3.8	.21	.03	27
RESERVOIR 24--EMPIRE RESERVOIR										
May, 1981										
20 ...	1932	1.0	5.0	<.01	.02	.46	4.5	.22	.02	43
June										
16 ...	1433	1.0	4.7	.02	<.01	.06	4.6	.27	.04	35
July										
15 ...	1802	1.0	7.5	.02	.06	.13	7.3	.34	.04	30
Aug										
05 ...	1431	1.0	6.7	<.01	<.01	.30	6.4	<.01	.02	31
26 ...	1802	1.0	--	<.10	<.10	.17	7.6	.32	.02	36
27 ...	0502	1.0	--	<.10	<.10	.25	7.0	.27	.02	40

Table 6.--*Trace elements*

[Analyses by U.S. Geological Survey. Abbreviations and symbol: m, meter; µg/L, microgram per liter; <, less than]

Date	Time (24-hour)	Sampling depth (m)	Copper, dissolved (µg/L as Cu)	Copper, total recoverable (µg/L as Cu)	Iron, dissolved (µg/L as Fe)	Lead, total recoverable (µg/L as Pb)	Lead, dissolved (µg/L as Pb)	Manganese, total recoverable (µg/L as Mn)	Manganese, dissolved (µg/L as Mn)
			RESERVOIR 1--AIR BASE POND						
May, 1981									
20 ...	0832	1.0	--	4	10	<1	--	50	10
20 ...	0836	3.0	--	3	10	<1	--	50	20
June									
15 ...	1503	1.0	--	4	30	12	--	90	7
15 ...	1507	3.0	--	3	20	12	--	100	8
July									
14 ...	1547	1.0	--	4	20	2	--	50	10
14 ...	1551	3.0	--	3	30	2	--	70	20
Aug									
04 ...	1603	1.0	--	6	15	<1	--	60	10
04 ...	1607	3.0	--	5	16	<1	--	130	75
24 ...	1802	1.0	1	4	11	6	4	80	21
24 ...	1806	3.0	1	4	31	5	3	150	58
25 ...	0502	1.0	1	4	20	3	<1	70	14
25 ...	0506	3.0	2	4	25	39	<1	130	52
			RESERVOIR 9--GAY RESERVOIR						
May, 1981									
20 ...	1403	1.0	--	5	50	<1	--	760	660
June									
16 ...	0903	1.0	--	3	70	15	--	190	120
July									
15 ...	0903	1.0	--	4	50	<1	--	160	50
Aug									
05 ...	0932	1.0	--	6	20	2	--	80	30
25 ...	1802	1.0	2	4	60	3	<1	40	20
26 ...	0502	1.0	2	5	60	6	4	40	20

Table 6.--*Trace elements*--Continued

Date	Time (24-hour)	Sampling depth (m)	Copper, dissolved (µg/L as Cu)	Copper, total recoverable (µg/L as Cu)	Iron, dissolved (µg/L as Fe)	Lead, total recoverable (µg/L as Pb)	Lead, dissolved (µg/L as Pb)	Manganese, total recoverable (µg/L as Mn)	Manganese, dissolved (µg/L as Mn)
			RESERVOIR 19--KING RESERVOIR						
May, 1981									
21 ...	0732	1.0	--	4	10	1	--	310	3
21 ...	0736	3.0	--	3	20	1	--	350	9
June									
16 ...	1803	1.0	--	4	40	15	--	420	2
16 ...	1807	3.0	--	3	<10	--	--	430	2
July									
15 ...	1432	1.0	--	4	<10	<1	--	440	4
15 ...	1436	3.0	--	4	10	2	--	600	170
Aug									
05 ...	1802	1.0	--	11	11	1	--	500	10
05 ...	1806	3.0	--	7	12	1	--	750	460
27 ...	1802	1.0	2	5	24	55	2	390	110
27 ...	1806	3.0	2	5	42	55	3	700	470
28 ...	0502	1.0	2	5	24	55	<1	390	72
28 ...	0506	3.0	2	5	30	60	<1	470	200
			RESERVOIR 24--EMPIRE RESERVOIR						
May, 1981									
20 ...	1932	1.0	--	8	280	1	--	200	40
June									
16 ...	1433	1.0	--	4	330	14	--	400	40
July									
15 ...	1802	1.0	--	5	110	2	--	930	<1
Aug									
05 ...	1431	1.0	--	7	60	2	--	780	6
26 ...	1802	1.0	2	5	58	50	3	780	7
27 ...	0502	1.0	2	5	55	60	3	830	9

Table 7.--*Taxa, percentage composition, and number of phytoplankton collected during 1981*

[m, meter; mL, milliliter]

	RESERVOIR 1--AIR BASE POND							
DATE:	May 20		May 20		June 15		June 15	
TIME (24-HOUR):	0832		0836		1503		1507	
DEPTH:	1.0 m		3.0 m		1.0 m		3.0 m	
	Cells per mL	Per-cent	Cells per mL	Per-cent	Cells per mL	Per-cent	Cells per mL	Per-cent
BACILLARIOPHYTA		1.9		2.2		0.57		1.2
Bacillariophyceae (diatoms)								
Amphipleura paludosa							4	.13
Cyclotella spp.	11	.50						
Cymbella minuta			3	.12			4	.13
Epithemia sorex	2	.09			8	.25	4	.13
Gomphonema spp.							4	.13
Navicula spp.	3	.14	3	.12	5	.16		
Nitzschia acicularis					5	.16	22	.69
N spp.			3	.12				
Synedra nana	18	.82	34	1.3				
S. ulna	7	.32	13	.50				
CHLOROPHYTA (green algae)		77		87		83		90
Chlorophyceae								
Actinastrum Hantzschii			3	.12				
Ankistrodesmus falcatus	210	9.6	520	20	290	9.1	260	8.1
Chodatella wratislavensis			6	.23				
Coelastrum microsporum	48	2.2	38	1.5	64	2.0	52	1.6
Cosmarium spp.					3	.09		
Crucigenia apiculata	8	.36	22	.85	59	1.8	61	1.9
C. tetrapedia	120	5.5	130	5.0	790	25	1,000	31
Dictyosphaerium pulchellum	2	.09						
Franceia ovalis					21	.66		
Gloeocystic gigas	89	4.1			84	2.6		
Oocystis crassa	10	.45						
O. lacustris	5	.23	9	.35	92	2.9		
O. parva	240	11	220	8.5	240	7.5	340	11
Pediastrum Boryanum	38	1.7	13	.50	49	1.5	78	2.4
P. duplex	23	1.1	13	.50	64	2.0	48	1.5
P. tetras							4	.13
Scenedesmus abundans	300	14	460	18	150	4.7	340	11
S. bijuga	30	1.4	53	2.0	160	5.0	160	5.0
S. dimorphus	23	1.1	34	1.3	5	.16	13	.41
S. opoliensis			3	.12				
S. protuberans	31	1.4	88	3.4	33	1.0		
S. quadricauda	210	9.6	330	13	170	5.3	270	8.4
Staurastrum spp.			3	.12	3	.09		
Tetraedron caudatum	5	.23						
T. minimum	250	11	190	7.3	59	1.8	70	2.1
T. pentaedricum	2	.09	9	.35	3	.09	9	.28
Tetrastrum staurogeniaeformae	38	1.7	110	4.2	320	10	170	5.3
CRYPTOPHYTA (cryptomonads)		5.1		4.3		16		7.2
Cryptophyceae								
Chroomonas sp.	110	5.0	110	4.2	190	5.9		
Crypt monas sp.	3	.14	3	.12	330	10	230	7.2
CYANOPHYTA (blue-green algae)		4.9		8.4		.47		.94
Cyanophyceae								
Aphanizomenon flos-aquae	13	.59	3	.12	10	.31	30	.94
Cyanarcus hamiformis	95	4.3	220	8.3	5	.16		
EUGLENOPHYTA (euglenoids)		.32		.12				
Euglenophyceae								
Euglena spp.	7	.32	3	.12				
PYRRHOPHYTA (fire algae)		11						
Dinophyceae (dinoflagellates)								
Gymnodinium spp.	250	11						
Total number of cells[1]	2,200		2,600		3,200		3,200	
Total number of taxa	31		30		27		22	

Table 7.--*Taxa, percentage composition, and number of phytoplankton collected during 1981*--Continued

	RESERVOIR 1--AIR BASE POND--Continued							
DATE:	July 14		July 14		August 4		August 4	
TIME (24-HOUR):	1547		1551		1603		1607	
DEPTH:	1.0 m		3.0 m		1.0 m		3.0 m	
	Cells per mL	Per-cent	Cells per mL	Per-cent	Cells per mL	Per-cent	Cells per mL	Per-cent
BACILLARIOPHYTA		.21		14		.55		7.2
Bacillariophyceae (diatoms)								
Cyclotella spp.			14	1.5				
Gomphonema spp.			3	.32				
Melosira granulata	3	.07	69	7.3				
Navicula spp.	3	.07	3	.32	13	.45	3	1.2
Nitzschia acicularis	3	.07	3	.32			1	.40
N. filformis			3	.32				
N. spp.			34	3.6			13	5.2
Rhoicosphemia curvata			3	.32	3	.10		
Synedra ulna							1	.40
CHLOROPHYTA (green algae)		92		79		54		52
Chlorophyceae								
Ankistrodesmus falcatus			7	.74				
Chlamydomonas spp.	2,900	71			1,400	48	35	14
Closteriopsis longissima			7	.74			1	.40
Coelastrum microsporum			10	1.1				
Cosmarium spp.	3	.07			3	.10	1	.40
Crucigenia tetrapedia	6	.15						
Oocystis crassa	150	3.7	240	26			8	3.2
O. parva	120	2.9	130	14				
Pediastrum Boryanum							1	.40
P. duplex			3	.32				
Quadrigula lacustris	9	.22	3	.32				
Scenedesmus abundans	3	.07	28	3.0			1	.40
S. bijuga					5	.17	1	.40
S. dimorphus			7	.74			1	.40
S. quadricauda	16	.39	58	6.2	5	.17	13	5.2
Schroederia setigera	520	13	230	24	160	5.5	66	26
Sphaerocystis Schroeteri			3	.32				
Tetraedron minimum			17	1.8	3	.10	1	.40
CRYPTOPHYTA (cryptomonads)		4.2		7.3		38		38
Cryptophyceae								
Chroomonas sp.	22	.54			610	21	18	7.2
Cryptomonas sp.	150	3.7	69	7.3	490	17	77	31
CYANOPHYTA (blue-green algae)		4.5				6.6		2.4
Cyanophyceae								
Anabaenae circinalis	3	.07						
Aphanizomenon flos-aquae	180	4.4			190	6.6	4	1.6
Oscillatoria spp.							1	.40
Spirulina spp.							1	.40
EUGLENOPHYTA (euglenoids)								.80
Euglena spp.							2	.80
Total number of cells[1]	4,100		940		2,900		250	
Total number of taxa	16		22		12		21	

Table 7.--*Taxa, percentage composition, and number of phytoplankton collected during 1981*--Continued

	RESERVOIR 1--AIR BASE POND--Cont.				RESERVOIR 9--GAY RESERVOIR			
DATE:	August 24		August 24		May 20		June 16	
TIME (24-HOUR):	1802		1806		1403		0903	
DEPTH:	1.0 m		3.0 m		1.0 m		1.0 m	
	Cells per mL	Percent	Cells per mL	Percent	Cells per mL	Percent	Cells per mL	Percent
BACILLARIOPHYTA		3.1		23		0.13		1.1
Bacillariophyceae (diatoms)								
Cocconies placentula	2	.15	3	1.2				
Gyrosigma macrum							2	.10
G. spp.			2	.80				
Melosira granulata	33	2.54	42	17				
Navicula spp.							1	.05
Nitzschia acicularis							19	.95
N. spp.	5	.38	10	4.0	3	.13		
CHLOROPHYTA (green algae)		45		17		21		39
Chlorophyceae								
Actinastrum Hantzschii					12	.52	440	22
Ankistrodesmus falcatus							45	2.2
Carteria spp.					470	20	290	15
Chlamydomnas spp.	400	31	7	2.8				
Cosmarium spp.	2	.15						
Oocystis spp.			3	1.2				
Quadrigula lacustris			3	1.2				
Scenedesmus abundans	4	.31	5	2.0				
S. dimorphous	2	.15						
S. quadricauda	4	.31	10	4.0				
Schroederia setigera	170	13						
Sphaerocystis Schroeteri			10	4.0				
Tetraedron minimum			5	2.0				
CRYPTOPHYTA (cryptomonads)		33		59		1.0		
Cryptophyceae								
Chroomonas sp.	200	15	120	48				
Cryptomonas sp.	240	18	28	11	23	1.0		
CYANOPHYTA (blue-green algae)		14		2.0		54		45
Cyanophyceae								
Anabaena Augustumalis					440	19	28	1.4
A. circinalis	5	.38						
A. spiroides					800	35	5	.25
Aphanizomenon flos-aquae	170	13	3	1.2				
Coelosphaerium Kuetzingianum			2	.80				
Gomphosphaeria lacustris							64	3.2
Lyngbya sp.					9	.39		
Microcystis aeruginosa	5	.38						
Oscillatoria spp.	2	.15						
Pseudoanabaena spp.							810	40
EUGLENOPHYTA (euglenoids)						23		4.8
Euglenophyceae								
Euglena acus					100	4.4	95	4.8
Lepocinclis spp.					410	18		
Phacus spp.					6	.26		
PYRRHOPHYTA (fire algae)		.69				1.4		9.8
Dinophyceae (dinoflagellates)								
Ceratium hirudinella	2	.15						
Gymnodinium spp.					32	1.4	190	9.5
Peridinium spp.	7	.54					7	.35
Total number of cells[1]	1,300		250		2,300		2,000	
Total number of taxa	17		15		11		13	

Table 7.--*Taxa, percentage composition, and number of phytoplankton collected during 1981*--Continued

	RESERVOIR 9--GAY RESERVOIR--Continued					
DATE:	July 15		August 5		August 25	
TIME (24-HOUR):	0903		0932		1802	
DEPTH:	1.0 m		1.0 m		1.0 m	
	Cells per mL	Per-cent	Cells per mL	Per-cent	Cells per mL	Per-cent
BACILLARIOPHYTA		65		1.2		2.9
Bacillariophyceae (diatoms)						
Amphipleura paludosa					16	.23
Chaetoceros muelleri	14	.67			170	2.4
Cyclotella spp.	10	.48				
Gyrosigma macrum	13	.62				
Navicula spp.	17	.81				
Nitzschia acicularis	1,300	62	150	1.2	16	.23
CHLOROPHYTA (green algae)		18		20		1.7
Chlorophyceae						
Actinastrum Hantzschii	6	.29	400	3.1	16	.23
Ankistrodesmus falcatus	140	6.7	2,100	16	47	.66
Carteria spp.	130	6.2				
Dictyosphaerium pulchellum	10	.48				
Scenedesmus opoliensis	10	.48	62	.48	40	.56
Tetraedron minimum	55	2.6	53	.41		
Treubaria setigerum	34	1.6	9	.07	16	.23
CRYPTOPHYTA (cryptomonads)		3.6		40		30
Cryptophyceae						
Chroomonas sp.	58	2.8	2,100	16	900	13
Cryptomonas sp.	17	.81	3,100	24	1,200	17
CYANOPHYTA (blue-green algae)		2.0		33		55
Cyanophyceae						
Anabaena spiroides	7	.33	1,800	14	190	2.7
Gomphosphaeria lacustris	27	1.3	9	.07	32	.45
Merismopedia tenuissima	7	.33	18	.14		
Pseudoanabaena spp.			2,500	19	3,700	52
EUGLENOPHYTA (euglenoids)		1.4		.96		.11
Euglenophyceae						
Euglena acus	27	1.3	71	.55		
Phacus spp.	3	.14	53	.41	8	.11
PYRRHOPHYTA (fire algae)		10		2.2		10
Dinophyceae (dinoflagellates)						
Glenodinium spp.					16	.23
Gymnodinium spp.	130	6.2				
Peridinium spp.	79	3.8	280	2.2	740	10
Total number of cells[1]	2,100		13,000		7,100	
Total number of taxa	21		15		15	

Table 7.--*Taxa, percentage composition, and number of phytoplankton collected during 1981*--Continued

	RESERVOIR 19--KING RESERVOIR							
DATE:	May 21		May 21		June 16		June 16	
TIME (24-HOUR):	0732		0736		1803		1807	
DEPTH:	1.0 m		3.0 m		1.0 m		3.0 m	
	Cells per mL	Per-cent	Cells per mL	Per-cent	Cells per mL	Per-cent	Cells per mL	Per-cent
BACILLARIOPHYTA		6.4		13		14		15
Bacillariophyceae (diatoms)								
Amphipleura paludosa			30	.52				
Nitzschia dissipata	51	.13						
N. palea spp.	2,400	6.0	650	11	3,700	10	1,000	10
Rhizosolenia longiseta					76	.21		
Stephanodiscus spp.	100	.25	59	1.0	1,400	3.9	450	4.6
CHLOROPHYTA (green algae)		20		41		68		63
Chlorophyceae								
Actinastrum Hantzschii	2,300	5.8	1,000	17.24				
Ankistrodesmus falcatus	1,900	4.8	510	8.8	4,800	13	700	7.1
Chodatella wratislavensis							28	.29
Coelastrum microsporum	610	1.5			2,400	6.7	450	4.6
Dictyosphaerium pulchellum	556	1.4			11,000	31	3,100	32
Dimorphococcus lunatus					300	.83	450	4.6
Elakatothrix gelatinosa					300	.83		
Franceia ovalis					210	.58		
Pediastrum tetras					300	.83		
Scenedesmus abundans	200	.50			530	1.5	140	1.4
S. dimorphous	1,100	2.8	450	7.8	1,600	4.4	280	2.9
S. opoliensis							250	2.6
S. quadricauda	560	1.4	300	5.2			56	.57
S. spp.					1,300	3.6		
Selenastrum minutum					150	.42	340	3.5
Tetraedron minimum	610	1.5	89	1.5	1,600	4.4	220	2.2
Tetrastrum staurogeniaeformae	250	.63	30	.52	76	.21	170	1.7
CRYPTOPHYTA (cryptomonads)		3.0		11		3.9		4.6
Cryptophyceae								
Cryptomonas sp.	1,200	3.0	620	11	1,400	3.9	450	4.6
CYANOPHYTA (blue-green algae)		69		34		12		17
Cyanophyceae								
Anabaena spiroides					76	.21		
A. spp.	100	.25	180	3.1				
Aphanocapsa elachista							56	.57
Merismopedia tenuissima	760	1.9						
Oscillatoria spp.	2,000	5.0	540	9.3	4,300	12	1,600	16
Pseudoanabaena spp.	25,000	62	1,300	22				
EUGLENOPHYTA (euglenoids)		.13		.52		.63		.57
Euglenophyceae								
Euglena spp.					76	.21		
Phacus spp.	51	.13	30	.52			56	.57
Trachelomonas hispida					76	.21		
T. spp.					76	.21		
Total number of cells[1]	40,000		5,800		36,000		9,800	
Total number of taxa	18		14		22		18	

Table 7.--*Taxa, percentage composition, and number of phytoplankton collected during 1981*--Continued

	RESERVOIR 19--KING RESERVOIR--Continued							
DATE:	July 15		July 15		August 5		August 5	
TIME (24-HOUR):	1432		1436		1802		1806	
DEPTH:	1.0 m		3.0 m		1.0 m		3.0 m	
	Cells per mL	Percent	Cells per mL	Percent	Cells per mL	Percent	Cells per mL	Percent
BACILLARIOPHYTA				1.4		1.0		1.4
Bacillariophyceae (diatoms)								
Nitzschia spp.							300	.64
Stephanodiscus spp.			570	1.4	430	1.0	380	.81
CHLOROPHYTA (green algae)		63		84		76		79
Chlorophyceae								
Actinastrum Hantzschii	63	.15						
Ankistrodesmus falcatus	9,600	22	14,000	34	7,100	17	13,000	28
Chodatella wratislavensis					1,000	2.3	1,400	3.0
Coelastrum microsporum	1,000	2.3	760	1.8	6,500	15	4,800	10
Crucigenia apiculata	250	.58	95	.23	160	.37	380	.81
C. spp.			950	2.3				
Dictyosphaerium pulchellum	250	.58	1,200	2.9	830	1.9		
Elakatothrix gelatinosa	63	.15					150	.32
Golenkinea radiata	5,000	12	5,600	14	1,100	2.6	160	.34
Scenedesmus abundans	1,300	3.0	2,000	4.9	2,800	6.5	2,300	4.9
S. dimorphous	3,900	9.1	3,100	7.6	8,400	20	7,800	17
S. opoliensis	250	.58	570	1.4	490	1.1	830	1.8
S. quadricauda					100	.23	300	.64
S. spp.					330	.77	76	.16
Selenastrum minutum	2,000	4.7	3,300	8.1	1,000	2.3	2,100	4.5
Tetraedron minimum	2,800	6.5	1,900	4.6	1,900	4.4	2,300	4.9
T. trigonum							76	.16
Tetrastrum staurogeniaeformae	700	1.6	760	1.8	810	1.9	1,200	2.6
Treubaria setigerum	63	.15	190	.46			150	.32
CRYPTOPHYTA (cryptomonads)		30		11		18		4.2
Cryptophyceae								
Chroomonas sp.	13,000	30	4,700	11	6,400	15	1,600	3.4
Cryptomonas sp.	130	.30			1,500	3.5	380	.81
CYANOPHYTA (blue-green algae)		4.7		3.0		5.6		16
Cyanophyceae								
Aphanothece nidulans					380	.88	76	.16
Chroococcus Prescottii					430	1.0		
Gomphosphaeria spp.			95	.23			230	.49
Merismopedia tenuissima	250	.58	280	.68			6,600	14
Microcystis aeruginosa					380	.88	76	.16
Oscillatoria spp.	1,000	2.3	660	1.6	1,200	2.8	460	.98
Pseudoanabaena spp.	760	1.8	190	.46				
EUGLENOPHYTA (euglenoids)		.30				.36		
Euglenophyceae								
Euglena spp.					100	.23		
Phacus spp.	130	.30			54	.13		
Total number of cells[1]	43,000		41,000		43,000		47,000	
Total number of taxa	19		19		23		25	

Table 7.--*Taxa, percentage composition, and number of phytoplankton collected during 1981*--Continued

	RESERVOIR 19--KING RESERVOIR-Cont.				RESERVOIR 24--EMPIRE RESERVOIR			
DATE: TIME (24-HOUR): DEPTH:	August 27 1802 1.0 m		August 27 1806 3.0 m		May 20 1932 1.0 m		June 16 1433 1.0 m	
	Cells per mL	Per-cent	Cells per mL	Per-cent	Cells per mL	Per-cent	Cells per mL	Per-cent
BACILLARIOPHYTA		.23		1.9		46		29
Bacillariophyceae (diatoms)								
Cyclotella spp.			510	1.6				
Navicula spp.	84	.23	84	.26	190	1.2		
Nitzschia acicularis					140	.88	350	.66
N. palea					7,100	44	15,000	28
CHLOROPHYTA (green algae)		86		76		9.9		24
Chlorophyceae								
Actinastrum Hantzschii					240	1.5		
Ankistrodesmus falcatus	11,000	31	8,400	26	810	5.1	4,200	7.9
Chodatella wratislavensis	670	1.7					230	.43
Coelastrum microsporum			2,000	6.2				
Cosmarium spp.							120	.23
Crucigenia apiculata	840	2.3						
Dictyosphaerium pulchellum	340	.94	1,000	3.1				
Gloeocystis spp.					47	.29		
Kirchneriella contorta							120	.23
Pediastrum duplex							120	.23
P. tetras	170	.47						
Scenedesmus abundans	1,300	3.6	340	1.1			230	.43
S. dimorphous	11,000	31	11,000	34	140	.88	1,900	3.5
S. opoliensis	420	1.2						
S. quadricauda					95	.59		
S. spp.							930	1.8
Selenastrum Bibraianum							120	.23
S. minutum	1,000	2.8	170	.53	240	1.5	3,400	6.4
Tetraedron minimum	1,700	4.7	1,000	3.1			1,000	1.9
Tetrastrum staurogeniaeformae	1,800	5.0	510	1.6			230	.43
Treubaria setigerum	590	1.6					230	.43
CRYPTOPHYTA (cryptomonads)		6.9		3.9		15		22
Cryptophyceae								
Chroomonas	2,300	6.4	1,000	3.1	660	4.1	470	.89
Cryptomonas sp.	170	.47	250	.78	1,700	11	11,000	21
CYANOPHYTA (blue-green algae)		7.8		17		26		14
Cyanophyceae								
Anabaena affinis					760	4.8	1,600	3.0
Aphanocapsa elachista	250	.69	420	1.3				
A. spp.							120	.23
Chroococcus spp.							230	.43
Merismopedia tenuissima	1,200	3.3	5,000	16			2,800	5.3
Microcystis aeruginosa	420	1.2						
Pseudoanabaena spp.	930	2.6			3,300	21	2,900	5.5
EUGLENOPHYTA (euglenoids)		.46		1.6		2.4		11
Euglenophyceae								
Euglena spp.	84	.23	510	1.6	140	.88	230	.43
Phacus spp.	84	.23					120	.23
Trachelomonas hispida					240	1.5	1,000	1.9
T. spp.							4,400	8.3
Total number of cells[1]	36,000		32,000		16,000		53,000	
Total number of taxa	21		15		15		26	

Table 7.--*Taxa, percentage composition, and number of phytoplankton collected during 1981*--Continued

RESERVOIR 24--EMPIRE RESERVOIR--Continued

DATE: TIME (24-HOUR): DEPTH:	July 15 1802 1.0 m		August 5 1431 0.5 m		August 26 1802 1.0 m	
	Cells per mL	Percent	Cells per mL	Percent	Cells per mL	Percent
BACILLARIOPHYTA		9.1		14		25
Bacillariophyceae (diatoms)						
Cyclotella striata	810	1.4	220	.28		
Nitzschia acicularis					76	.12
N. palea	3,600	6.4	10,000	13	14,000	22
N. spp.	710	1.3	330	.42	1,500	2.4
Rhizosolenia longiseta					150	.24
CHLOROPHYTA (green algae)		76		51		36
Chlorophyceae						
Ankistrodesmus falcatus	9,400	17	11,000	14	11,000	17
Chodatella quadriseta	200	.36	220	.28	150	.24
C. wratislavensis			330	.42	76	.12
Coelastrum microsporum	2,500	4.5	5,000	6.4	460	.73
Cosmarium spp.	910	1.6	1,600	2.1	1,700	2.7
Crucigena crucifera	510	.91				
C. spp.	2,100	3.8	1,200	1.5		
Dimorphococcus lunatus	14,000	25	3,500	4.5	1,100	1.8
Elakatothrix viridis	300	.54			150	.24
Pediastrum Boryanum			110	.14		
P. duplex	300	.54			76	.12
Scenedesmus abundans					76	.12
S. acuminatus	2,300	4.1	2,300	3.0	680	1.1
S. arcuatus	200	.36				
S. dimorphous	510	.91				
S. producto-capitatus	510	.91	1,900	2.4	1,200	1.9
S. protuberans	400	.71	330	.42	150	.24
S. quadricauda	1,200	2.1	970	1.2	76	.12
S. verrucosus	100	.18	540	.69	1,400	2.2
S. spp.	610	1.1	1,300	1.7	230	.37
Selenastrum Bibraianum	1,000	1.8	540	.69		
S. gracilis	200	.36				
S. minutum	2,600	4.6	6,100	7.8	1,700	2.7
S. Westii					76	.12
Tetraedron hastatum	100	.18				
T. minimum	2,400	4.3	1,600	2.1	2,000	3.2
T. trigonum			760	.97	760	1.2
Tetrastrum staurogeniaeformae	200	.36	220	.28	76	.12
Treubaria setigerum			220	.28		
CRYPTOPHYTA (cryptomonads)		2.3		.69		1.9
Cryptophyceae						
Cryptomonas sp.	1,300	2.3	540	.69	1,200	1.9
CYANOPHYTA (blue-green algae)		11		29		15
Cyanophyceae						
Anabaena affinis					1,200	1.9
A. spp.					530	.84
Aphanocapsa spp.					76	.12
Coelosphaerium spp.			870	1.1	230	.37
Merismopedia tenuissima			15,000	19	5,800	9.2
Oscillatoria spp.	5,900	11	6,800	8.7	1,900	3.0
EUGLENOPHYTA (euglenoids)		2.5		5.4		21
Euglenophyceae						
Euglena spp.	510	.91	1,200	1.5	1,200	1.9
Phacus spp.					300	.48
Trachelomonas hispida			650	.83	990	1.6
T. spp.	910	1.6	2,400	3.1	11,000	17
PYRRHOPHYTA (fire algae)		.36		.28		.12
Dinophyceae (dinoflagellates)						
Peridinium spp.	200	.36	220	.28	76	.12
Total number of cells[1]	56,000		78,000		63,000	
Total number of taxa	31		31		36	

[1]Total number of cells rounded to two significant figures. Percents are calculated from unrounded values.

Table 8.--*Taxa, percentage composition, and number of zooplankton collected during 1981*

[m, meter; L, liter]

	Reservoir 1--Air Base Pond							
Date:	May 20		May 20		June 15		June 15	
Time (24-hour):	0832		0836		1503		1507	
Depth:	1.0 m		3.0 m		1.0 m		3.0 m	
	Organisms per L	Percent	Organisms per L	Percent	Organisms per L	Percent	Organisms per L	Percent
ROTIFERA								
Monogononta		3.6				2.3		
Ploima								
Brachionus sp.	2	3.6						
Keratella cochlearis					2	2.3		
ARTHROPODA		96				98		100
Crustacea								
Cladocera								
Bosmina longirostris					11	12	18	6.2
Daphnia ambigua	8	14			33	38	130	45
Daphnia thorata					2	2.3	55	19
Copepoda								
Cyclops bicuspidatus thomasi	45	82	120	100	40	46	88	30
Total number of organisms[1]	55		120		88		290	
Total number of taxa	3		1		5		4	

	Reservoir 1--Air Base Pond--Continued							
Date:	July 14		July 14		August 4		August 4	
Time (24-hour):	1547		1551		1603		1607	
Depth:	1.0 m		3.0 m		1.0 m		3.0 m	
	Organisms per L	Percent	Organisms per L	Percent	Organisms per L	Percent	Organisms per L	Percent
ARTHROPODA		100		100		100		100
Crustacea								
Cladocera								
Bosmina longirostris	11	17	4	2.9	10	4.6	2	.73
Daphnia ambigua	9	14	28	20	67	31	44	16
Daphnia thorata	23	35	73	53	40	19	85	31
Copepoda								
Cyclops bicuspidatus thomasi	23	35	34	24	99	46	140	52
Total number of organisms[1]	66		140		220		270	
Total number of taxa	4		4		4		4	

Table 8.--*Taxa, percentage composition, and number of zooplankton collected during 1981*--Continued

	Reservoir 1--Air Base Pond-Cont.				Reservoir 9--Gay Reservoir			
Date:	August 24		August 24		May 20		June 16	
Time (24-hour):	1802		1806		1403		0903	
Depth:	1.0 m		3.0 m		1.0 m		1.0 m	
	Organisms per L	Percent	Organisms per L	Percent	Organisms per L	Percent	Organisms per L	Percent
ARTHROPODA		100		100		100		100
Crustacea								
Cladocera								
Bosmina longirostris	2	11	2	2.7				
Daphnia ambigua	2	11	43	59			4	100
Daphnia thorata			4	5.5				
Copepoda								
Cyclops bicuspidatus thomasi	15	79	24	33	22	100		
Total number of organisms[1]	19		73		22		4	
Total number of taxa	3		4		1		1	

	Reservoir 9--Gay Reservoir--Continued					
Date:	July 15		August 5		August 25	
Time (24-hour):	0903		0932		1802	
Depth:	1.0 m		1.0 m		1.0 m	
	Organisms per L	Percent	Organisms per L	Percent	Organisms per L	Percent
ARTHROPODA		100		100		100
Crustacea						
Copepoda						
Cyclops bicuspidatus thomasi	9	100	12	100	16	100
Total number of organisms[1]	9		12		16	
Total number of taxa	1		1		1	

Table 8.--*Taxa, percentage composition, and number of zooplankton collected during 1981*--Continued

	Reservoir 19--King Reservoir							
Date:	May 21		May 21		June 16		June 16	
Time (24-hour):	0732		0736		1803		1807	
Depth:	1.0 m		3.0 m		1.0 m		3.0 m	
	Organisms per L	Percent	Organisms per L	Percent	Organisms per L	Percent	Organisms per L	Percent
ARTHROPODA		100		100		100		100
Crustacea								
Cladocera								
Bosmina longirostris	44	21	10	3.8				
Daphnia ambigua	20	9.3	20	7.6	2	2.2	4	3.3
Daphnia catawba			4	1.5			2	1.6
Copepoda								
Cyclops bicuspidatus thomasi	130	63	210	81	43	46	69	57
Diaptomus sp.	16	7.5	16	6.1	48	52	46	38
Total number of organisms[1]	210		260		93		120	
Total number of taxa	4		5		3		4	

	Reservoir 19--King Reservoir--Continued							
Date:	July 15		July 15		August 5		August 5	
Time (24-hour):	1432		1436		1802		1806	
Depth:	1.0 m		3.0 m		1.0 m		3.0 m	
	Organisms per L	Percent	Organisms per L	Percent	Organisms per L	Percent	Organisms per L	Percent
ARTHROPODA		100		100		100		100
Crustacea								
Cladocera								
Bosmina longirostris	2	6.2			2	3.8		
Daphnia ambigua	4	12			2	3.8		
Daphnia catawba							4	8.3
Copepoda								
Cyclops bicuspidatus thomasi	14	44	58	35	13	25	5	10
Diaptomus sp.	12	38	106	65	36	68	39	81
Total number of organisms[1]	32		170		53		48	
Total number of taxa	4		2		4		3	

Table 8.--*Taxa, percentage composition, and number of zooplankton collected during 1981*--Continued

	Reservoir 19--King Reservoir--Cont.				Reservoir 24--Empire Reservoir			
Date:	August 27		August 27		May 20		June 16	
Time (24-hour):	1802		1806		1932		1433	
Depth:	1.0 m		3.0 m		1.0 m		1.0 m	
	Organisms per L	Percent	Organisms per L	Percent	Organisms per L	Percent	Organisms per L	Percent
ROTIFERA								
Monogononta								5.5
Ploima								
Keratella cochlearis							11	5.5
ARTHROPODA		100		100		100		94.47
Crustacea								
Cladocera								
Bosmina longirostris	2	7.7					24	12
Daphnia ambigua	9	35					2	1.0
Daphnia catawba	4	15	2	1.5				
Copepoda								
Cyclops bicuspidatus thomasi			8	5.9	18	100	160	80
Diaptomus sp.	11	42	120	93			3	1.5
Total number of organisms[1]	26		130		18		200	
Total number of taxa	4		3		1		5	

	Reservoir 24--Empire Reservoir--Continued					
Date:	July 15		August 5		August 26	
Time (24-hour):	1802		1431		1802	
Depth:	1.0 m		0.5 m		1.0 m	
	Organisms per L	Percent	Organisms per L	Percent	Organisms per L	Percent
ARTHROPODA		100		100		100
Crustacea						
Cladocera						
Bosmina longirostris	49	34			7	10
Daphnia ambigua	2	1.4			2	2.9
Copepoda						
Cyclops bicuspidatus thomasi	80	56	20	50	50	74
Diaptomus sp.	12	8.4	20	50	9	13
Total number of organisms[1]	140		40		68	
Total number of taxa	4		2		4	

[1]Total number of cells are rounded to two significant figures. Percents are calculated from unrounded values.

Table 9.--*Taxa, percentage composition, and number of benthic invertebrates collected during August 1981*

[m^2, square meter]

	RESERVOIR 1--AIR BASE POND							
Sampling location:	Middle of reservoir		4.6 meters (15 feet) from shore		At shore		Average	
	Organisms per m^2	Percent	Organisms per m^2	Percent	Organisms per m^2	Percent	Organisms per m^2	Percent
ANNELIDA		31		14		50		23
Oligochaeta (aquatic worms)	1,900	31	820	14	87	50	940	23
ARTHROPODA		67		85		25		75
Insecta								
Diptera (true flies)								
Ceratopogomidae	87	1.4	87	1.5			44	1.1
Chironomidae								
Chironomus sp.	3,400	56	4,000	68			2,500	61
Chryptochironomus sp.	87	1.4					29	.71
Glyptotendipes sp.			130	2.2			43	1.1
Procladius sp.	480	7.7	780	13			420	10
Hemiptera (aquatic bugs)								
Corixidae	43	.70			43	25	29	.71
MOLLUSCA		2.1		1.5		25		2.1
Gastropoda (snails)								
Lymnaeidae								
Lymnaea sp.			43	.73			14	.34
Physidae								
Physa sp.					43	25	14	.34
Pelecypoda (bivalves)								
Sphaeriidae	130	2.1	43	.73			58	1.4
Total number of organisms[1]	6,100		5,900		170		4,100	
Total number of taxa	7		7		3		10	

Table 9.--*Taxa, percentage composition, and number of benthic invertebrates collected during August 1981*--Continued

	RESERVOIR 9--GAY RESERVOIR							
Sampling location:	Middle of reservoir		4.6 meters (15 feet) from shore		At shore		Average	
	Organisms per m^2	Percent	Organisms per m^2	Percent	Organisms per m^2	Percent	Organisms per m^2	Percent
ANNELIDA		12		67		9.3		41
Hirudinea (leeches)			43	.98			14	.52
Oligochaeta (aquatic worms)	220	12	2,900	66	170	9.3	1,100	41
ARTHROPODA		23		29		80		39
Crustacea								
Amphipoda (scuds)								
Talitridae								
Hyallela azteca			87	1.99	173	9.29	87	3.23
Insecta				26.72		69.78		35.82
Diptera (true flies)								
Ceratopogonidae			43	.98			14	.52
Chironomidae								
Chironomus sp.	170	9.3					58	2.2
Chryptochironomus sp.	170	9.3	390	8.9	87	4.7	220	8.0
Einfeldia sp.			350	7.9			120	4.3
Glyptotendipes sp.			220	4.9	130	7.0	120	4.3
Parachironomus sp.					87	4.7	29	1.1
Paratanytarsus sp.					130	7.0	43	1.6
Procladius sp.					87	4.7	29	1.1
Ephemeroptera (mayflies)								
Baetidae								
Baetis sp.	43	2.3					14	.52
Caenidae								
Caenis sp.					170	9.3	58	2.2
Hemiptera (aquatic bugs)								
Corixidae			170	4.0	220	12	130	4.8
Odonata (dragonflies)								
Coenagrionidae								
Ishnura sp.	43	2.3			390	21	140	5.3
MOLLUSCA		65		4.0		12		20
Gastropoda (snails)								
Physidae								
Physa sp.	390	21			130	7.0	170	6.4
Planorbidae					87	4.7	29	1.1
Pelecypoda (bivalves)								
Sphaeriidae	820	44	170	4.0			330	12
Total number of organisms[1]	1,900		4,400		1,900		2,700	
Total number of taxa	7		9		12		18	

Table 9.--*Taxa, percentage composition, and number of benthic invertebrates collected during August 1981*--Continued

	RESERVOIR 19--KING RESERVOIR							
Sampling location:	Middle of reservoir		4.6 meters (15 feet) from shore		At shore		Average	
	Organisms per m^2	Percent	Organisms per m^2	Percent	Organisms per m^2	Percent	Organisms per m^2	Percent
ANNELIDA		82		28				32
Oligochaeta (aquatic worms)	2,300	82	1,500	28			1,300	32
ARTHROPODA		18		70		98		67
Crustacea								
Amphipoda (scuds)								
Talitridae								
Hyallela azteca			43	.83	87	2.3	43	1.1
Insecta								
Diptera (true flies)								
Ceratopogonidae			43	.83	43	1.1	29	.74
Chironomidae								
Chironomus sp	480	17	3,000	58	2,600	68	2,000	51
Chryptochironomus sp.			43	.83	740	20	260	6.6
Einfeldia sp.			220	4.2			72	1.8
Procladius sp.	43	1.5	43	.83	130	3.4	72	1.8
Hemiptera (aquatic bugs)								
Corixidae			220	4.2			72	1.8
Odonata (dragonflies)								
Coenagrionidae								
Ishnura sp.					130	3.4	43	1.1
MOLLUSCA				1.7		2.2		1.5
Gastropoda (snails)								
Planorbidae					43	1.1	14	.36
Pelecypoda (bivalves)				1.7		1.1		1.1
Sphaeriidae			87	1.7	43	1.1	43	1.1
Total number of organisms[1]	2,800		5,200		3,800		3,900	
Total number of taxa	3		9		8		11	

Table 9.--*Taxa, percentage composition, and number of benthic invertebrates collected during August 1981*--Continued

Sampling location:	RESERVOIR 24--EMPIRE RESERVOIR							
	Middle of reservoir		4.6 meters (15 feet) from shore		At shore		Average	
	Organisms per m^2	Percent	Organisms per m^2	Percent	Organisms per m^2	Percent	Organisms per m^2	Percent
ANNELIDA		31		92		5.9		43
Hirudinea (leeches)	43	1.0	87	.74			43	.43
Oligochaeta (aquatic worms)	1,300	30	11,000	91	820	5.9	4,200	43
ARTHROPODA		69		8.5		94		57
Crustacea								
Amphipoda (scuds)								
Talitridae								
Hyallela azteca					12,000	85	4,000	40
Insecta								
Diptera (true flies)								
Chironomidae								
Chironomus sp.	2,900	68	820	7.0			1,200	12
Chryptochironomus sp.			87	.74			29	.29
Einfeldia sp.					820	5.9	270	2.8
Glyptotendipes sp.					87	.62	29	.29
Kiefferulus sp.			43	.37			14	.14
Procladius sp.			43	.37			14	.14
Hemiptera (aquatic bugs)								
Corixidae					350	2.5	120	1.2
Notonectidae								
Notonecta sp.	43	1.0					14	.14
Total number of organisms[1]	4,300		12,000		14,000		9,900	
Total number of taxa	4		6		5		11	

[1]Total number of organisms rounded to two significant figures. Percents are calculated from unrounded values.

Table 10.--*Bacterial concentration of samples collected from May through August 1981*

[Concentration in number of organisms per 100 milliliters. <, less than; >, greater than]

Sample information	Bacteria														
	Fecal coliform (FC)					Fecal streptococci (FS)					FC/FS ratio[1]				
RESERVOIR 1--AIR BASE POND															
Date	5-20	6-15	7-14	8-4	8-24	5-20	6-15	7-14	8-4	8-24	5-20	6-15	7-14	8-4	8-24
Concentration at mid-reservoir	[2]4	[2]10	[2]45	[2]4	21	[2]7	[2]16	23	[2]6	74	[3].57	[3].63	2.0	[3].67	.28
Concentration near shore	[2]2	[2]14	35	[2]5	27	[2]5	[2]13	31	74	37	[3].40	[3]1.1	1.1	[3].068	.73
RESERVOIR 9--GAY RESERVOIR															
Date	5-20	6-16	7-15	8-5	8-25	5-20	6-16	7-15	8-5	8-25	5-20	6-16	7-15	8-5	8-25
Concentration at mid-reservoir	[2]1	[2]3	21	[2]5	60	[2]<1	[2]13	[2]18	[2]9	[2]2	[3]>1.0	[3].23	1.2	[3].56	30
Concentration near shore	[2]1	[2]3	[2]12	[2]12	48	[2]<1	[2]5	180	36	28	[3]>1.0	[3].60	[3].067	[3].33	1.7
RESERVOIR 19--KING RESERVOIR															
Date	5-21	6-16	7-15	8-5	8-27	5-21	6-16	7-15	8-5	8-27	5-21	6-16	7-15	8-5	8-27
Concentration at mid-reservoir	750	130	[2]20	[2]25	[2]45	170	120	[2]20	[2]5	<5	4.4	1.1	[3]1.0	[3]5.0	[3]>9.0
Concentration near shore	[2]1,100	[2]330	[2]22	[2]35	[2]20	208	378	[2]18	[2]10	[2]40	[3]5.3	[3].87	[3]1.2	[3]3.5	[3].50
RESERVOIR 24--EMPIRE RESERVOIR															
Date	5-20	6-16	7-15	8-5	8-26	5-20	6-16	7-15	8-5	8-26	5-20	6-16	7-15	8-5	8-26
Concentration at mid-reservoir	[2]990	[2]110	[2]90	[2]10	120	390	85	135	160	[2]20	[3]2.5	[3]1.3	[3].67	[3].063	[3]6.0
Concentration near shore	560	100	100	[2]65	160	370	78	87	[2]50	[2]35	1.5	1.3	1.2	[3]1.3	[3]4.6

[1] Fecal coliform organisms per 100 milliliters divided by fecal streptococcal organisms per 100 milliliters

[2] Estimated concentration based on nonideal colony count

[3] FC/FS ratio based on nonideal colony counts

*GPO 691-922 (1985)